Mineral Resource Report

MRR 2005-5

New Nouveau
Brunswick

Natural Resources
Minerals, Policy and Planning

STRATIGRAPHY, STRUCTURAL GEOLOGY, AND TECTONIC HISTORY OF THE McCULLY AREA, MONCTON SUBBASIN, SOUTHEASTERN NEW BRUNSWICK

Paul Wilson

ISSN 0713-2433
ISBN 1-55396-353-9
Price: $12.00

2005

Mineral Resource Report 2005-5

Stratigraphy, Structural Geology, and Tectonic History of the McCully Area, Moncton Subbasin, Southeastern New Brunswick

Recommended citation:

Wilson, P. 2005. Stratigraphy, structural geology, and tectonic history of the McCully area, Moncton subbasin, southeastern New Brunswick. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, 104 p.

This report has been published by:

Minerals, Policy and Planning Division
Department of Natural Resources
Province of New Brunswick

Hon. Keith Ashfield
Minister of Natural Resources

May 2005

New Nouveau
Brunswick

Natural Resources
Minerals, Policy and Planning

Mineral Resource Report 2005-5

STRATIGRAPHY, STRUCTURAL GEOLOGY, AND TECTONIC HISTORY OF THE MCCULLY AREA, MONCTON SUBBASIN, SOUTHEASTERN NEW BRUNSWICK

Paul Wilson

ISSN 0713-2433
ISBN 1-55396-353-9
Price: $12.00

2005

TABLE OF CONTENTS

Abstract iv
Resumé v
Acknowledgments 1
Introduction 1
  Objective 1
  Scope 1
  Background 1
Project Methodology 4
Lithostratigraphy 4
  Introduction 4
  Basement Complex 6
  Horton Group 6
  Moncton Group 8
  Windsor Group 9
  Mabou Group 11
  Cumberland and Pictou Groups 11
Structural Geology 12
  Structural geology of the Albert Formation 12
    Structure of the McCully gas field 12
    Surface structural geology of the Albert Formation 12
  Structural geology of the Windsor Group 17
  Fault kinematics and timing 25
  Summary of tectonic history 30
Discussion 31
  Implications for trapping mechanisms and reservoir porosity/permeability 31
  Salt tectonics 34
  Fault kinematics and tectonic setting of the Moncton Subbasin 36
  Mesozoic deformation 38
Conclusions and Recommendations 39
References 40

APPENDICES

APPENDIX 1. Summary logs of salt cores 47

Potash Company of America B-3 Summary Log 48
Potash Company of America C-4 Summary Log 50
Potash Company of America D-2A Summary Log 51
Potash Company of America D-3 Summary Log 54
Potash Company of America D-4 Summary Log 57
Potash Company of America E-4A Summary Log 62

Potash Company of America G-3A Summary Log 65
Potash Company of America G-4A Summary Log 67
Potash Company of America H-4A Summary Log 70
Potash Company of America H-5 Summary Log 72
Potash Company of America I-4 Summary Log 74
Potash Company of America M-4A Summary Log 76
Potash Company of America N-2 Summary Log 78
Potash Company of America N-3 Summary Log 79
Potash Company of America P-1 Summary Log 81
Potash Company of America P-4 Summary Log 83
Potash Company of America S-4 Summary Log 84
Potash Company of America T-3 Summary Log 87
Potash Company of America X-3 Summary Log 88
Potash Company of America X-6 Summary Log 91
Potash Company of America Z-4 Summary Log 92
Potash Corporation of Saskatchewan 02-04 Summary Log 93
Potash Company of America DD-4A Summary Log 95

APPENDIX 2. Interpretations of seismic reflection profiles 97

Interpretation of Corridor Resources Inc. Line 1 98
Interpretation of Corridor Resources Inc. Line 3 99
Interpretation of Corridor Resources Inc. Line 4 100
Interpretation of Corridor Resources Inc. reprocessed line 34Y 101
Interpretation of Potash Corporation of Saskatchewan Line PIC 1 102
Interpretation of Potash Corporation of Saskatchewan Line PIC 2 103
Interpretation of Potash Corporation of Saskatchewan Line PIC 3 104

TABLES

Table 1. Table of formations for the western Moncton Subbasin 7
2. Stratigraphy of the Windsor Group in the western Moncton Subbasin 10

FIGURES

Figure 1. Regional distribution of the Maritimes Basin 2
2. Map of the Maritimes Basin in southeast New Brunswick, showing the major faults 3
3. Interpretation of seismic line 6 6
4. Interpretation of seismic line 5 13
5. Interpretation of seismic line 2 14
6. Map showing the locations of outcrops referred to in section 4.1 15
7. Stereonets showing orientation data from the Highway 1 section 16
8. Geology of Highway 1 17

9. Faults in the Albert Formation ... 18
10. Thin sections of faults in the Albert Formation ... 18
11. Syn-sedimentary structures observed along Highway 1 ... 20
12. Structure contour map of the depth to top salt in metres below mean sea level ... 21
13. Cross-sections a to f of the Penobsquis salt structure ... 22
14. Interpretation of seismic line PIC-4 ... 24
15. (a) Folded Macumber limestone near the community water well at Sussex Corner, (b) Folded Macumber limestone at Sussex Corner ... 24
16. Photomicrographs of salt thin sections taken from borehole B-3 ... 26
17. Photomicrographs of cap rock samples taken from mineral exploration core ... 27
18. Outcrop of steeply dipping rippled sandstone of the Boss Point Formation near the H-28 wellsite ... 28
19. Model for the tectonic evolution of the McCully area ... 32

PLATE

(in back pocket)

Plate 1. Geological map of the study area. Modified after St. Peter (2002), with additional mapping and interpretation by the author.

ABSTRACT

The McCully area is located in the western part of the Late Devonian-Carboniferous Moncton Subbasin, immediately to the northeast of the town of Sussex. The area is of economic importance because of the presence of the Penobsquis salt structure, which contains potash and rock salt deposits in the Viséan Cassidy Lake Formatión (Windsor Group), and the presence of a petroleum system in the Tournaisian Albert Formation (Horton Group). However, despite its economic potential, the stratigraphy, structural geology and tectonic history of the area are incompletely understood. A study of the structural geology of this area, incorporating field, borehole and seismic data, has been undertaken by the author. The aim of the project was to understand the structural geology and three-dimensional architecture of the study area, with emphasis on the morphology, kinematics and timing of faults. The implications for emplacement and structural control of potash and rock salt deposits, and structural control of the petroleum system in the study area, are emphasized.

The McCully gas field lies within a northeast-trending, doubly plunging, anticlinal structure, approximately 12 km long and 5 km across. The trap is interpreted as a combined anticline/ unconformity trap. Thrust faulting may also be involved in trap formation. Study of faults in outcrop and in thin section suggest that it is possible that minor faults and tight folds related to major fault zones in the McCully gas field are associated with elevated porosity or permeability.

The Penobsquis salt structure is an elongate, approximátely northeast-trending salt wall that may be divided into two segments. The southwestern segment comprises an asymmetric, southeast-vergent fold trending approximately 055°. The northeastern segment comprises an overturned to recumbent, southeast-vergent fold trending approximately 070°. Both segments have been modified by dissolution processes. The salt structure is separated from underlying rocks by a detachment surface. Seismic and borehole evidence shows that the salt structure has a two-phase history. The structure initiated during Mabou Group deposition, and the main phase of salt deformation occurred after deposition of the Cumberland Group (Westphalian A), probably during Alleghenian orogenesis. The association of the salt structure with major reverse faults in the cover, the strong southeast-verging asymmetry of the structure, and the presence of internal low-angle reverse-sense shear zones, support this conclusion. The Moncton Subbasin is therefore an example of an inverted intracratonic salt basin.

The availability of new seismic, borehole and field evidence has produced revisions to the pre-Windsor stratigraphy of the Moncton Subbasin. Pre-Windsor strata are divided into two groups, the lower Horton Group and the upper Moncton Group. These stratigraphic revisions have led to a reinterpretation of the tectonic history of the Moncton Subbasin. The Subbasin is characterized by periods of deposition punctuated by periods of basin inversion marked by unconformities or disconformities. No evidence for strike-slip displacements on major faults greater than a few kilometres has been found, and it is argued that a mixed-mode oblique-slip model of basin formation is more realistic than a strike-slip model.

RÉSUMÉ

Le secteur de McCully est situé dans la partie occidentale du sous-bassin de Moncton allant du Dévonien tardif au Carbonifère, immédiatement au nord-est de la ville de Sussex. Le secteur a une importance économique en raison de la présence de la structure salifère de Penobsquis, qui abrite des gîtes de potasse et de sel gemme à l'intérieur de la Formation viséenne de Cassidy Lake (groupe de Windsor), ainsi que d'un système pétrolifère dans la Formation tournaisienne d'Albert (groupe de Horton). On ne comprend toutefois pas complètement la stratigraphie, la géologie structurale et le passé tectonique du secteur malgré son potentiel économique. L'auteur a réalisé une étude de la géologie structurale de ce secteur incorporant des données de terrain et de sondage et des données sismiques. Le projet visait à comprendre la géologie structurale et l'architecture tridimensionnelle du secteur d'étude, en mettant l'accent sur la morphologie, la cinématique et le moment de la formation des failles. Il s'attarde sur les répercussions de la mise en place et du contrôle structural des gîtes de potasse et de sel gemme de même que sur le contrôle structural du système pétrolifère à l'intérieur du secteur d'étude.

Le champ gazier de McCully se trouve à l'intérieur d'une structure anticlinale à double plongement orientée vers le nord-est ayant environ douze kilomètres de longueur et cinq kilomètres de largeur. Le piège à gaz est interprété en tant que piège anticlinal/discordant combiné. Des failles chevauchantes pourraient également avoir joué un rôle dans la formation du piège. Une étude des failles dans l'affleurement et dans un stratotype sous-dimensionné laissent supposer qu'il est possible que des plis serrés et des failles secondaires apparentés aux principales zones faillées du champ gazier de McCully soient associés à une porosité ou une perméabilité élevées.

La structure salifère de Penobsquis représente un filon de sel vertical allongé et orienté en gros vers le nord-est qui peut être subdivisé en deux segments. Le segment sud-ouest est constitué d'un pli asymétrique orienté à peu près à 55 ° vers le sud-est. Le segment nord-est est constitué d'un pli renversé à couché orienté à peu près à 70 ° vers le sud-est. Les deux segments ont été modifiés par des processus de dissolution. La structure salifère est séparée des roches sous-jacentes par une surface de décollement. Les observations des travaux sismiques et de sondage révèlent que le passé de la structure salifère a comporté deux phases. La structure a commencé à se former pendant la sédimentation du groupe de Mabou et la principale phase de la déformation saline est survenue après la sédimentation du groupe de Cumberland (Westphalien A), probablement au cours de l'orogenèse alléghanienne. L'association de la structure salifère avec les principales failles inverses dans la couverture, l'asymétrie prononcée de la structure vers le sud-est et la présence de zones de cisaillement inversées à faible pendage interne, confortent une telle conclusion. La sous-bassin de Moncton représente par conséquent un exemple d'un bassin salifère intracratonique inversé.

L'accessibilité de nouvelles observations de terrain, de sondages et de relevés sismiques a entraîné des révisions de la stratigraphie antérieure à Windsor du sous-bassin de Moncton. Les strates antérieures à Windsor sont subdivisées en deux groupes, le groupe inférieur de Horton et le groupe supérieur de Moncton. Ces modifications stratigraphiques ont suscité une réinterprétation du passé tectonique du sous-bassin de Moncton. Le sous-bassin est caractérisé par des périodes de sédimentation ponctuées d'intervalles d'inversion du bassin, marqués par des absences de concordance ou des discordances. Aucun indice de déplacement en coulissement suivant des failles importantes de plus de quelques kilomètres n'a été relevé; il est avancé qu'un modèle de formation du bassin à rejet oblique mixte est plus réaliste qu'un modèle à décrochement horizontal.

ACKNOWLEDGMENTS

Discussions with Clint St. Peter, Dr. David Keighley, Paul Durling, Dr. Tom Martel, Brian Roulston, Brian Urquhart, Jeff Curtis, Dr. Joe White, Dr. Adrian Park, and Dr. Murray Gingras have led to significant improvements in the author's understanding of the study area. Clint St. Peter, Dr. Joe White, and Paul Durling are further thanked for their constructive comments on the manuscript. Dr. Joe White is supervising the author's PhD thesis at the University of New Brunswick. Funding for this project was provided by the New Brunswick Department of Natural Resources, Geological Surveys Branch, and the Potash Corporation of Saskatchewan Inc. (PCS) New Brunswick Division.

INTRODUCTION

OBJECTIVE

The primary objectives of this study are to understand the structural geology, three-dimensional architecture, and tectonic history of the Late Devonian-Carboniferous rocks in the vicinity of the McCully gas field, immediately to the northeast of Sussex, New Brunswick. Special attention is paid to the morphology, kinematics, and timing of structures relevant to the structural control of the petroleum system in Albert Formation rocks of the McCully gas field, and to emplacement and control of potash deposits in the study area. Data from surface mapping, industry and public domain seismic reflection profiles, drill core from potash exploration holes, and well cuttings from the McCully gas field are integrated. This integrated study advances knowledge of the stratigraphy and structural geology of the area and contributes to the assessment of structural controls on: (1) sedimentation, (2) hydrocarbon traps, and (3) potash and salt emplacement. The implications of the data for the tectonic history and setting of the larger Maritimes Basin are evaluated.

SCOPE

This two-year project has mainly comprised the evaluation of subsurface data, including cores and cuttings from mineral and hydrocarbon exploration boreholes, and new or newly reprocessed seismic reflection data. The study area covers approximately 460 km^2. Rock exposures are limited and mainly restricted to stream channels and rare road cuts. Therefore, the only areas mapped in detail were those where structural or stratigraphic problems were identified from subsurface data (see below under Project Methodology).

BACKGROUND

The Moncton Subbasin is a substructure of the Upper Paleozoic Maritimes Basin. The Maritimes Basin (Roliff 1955; Williams 1974) is the largest intermontane basin in the Appalachian mountain chain, covering around 148 000 km^2, of which approximately two-thirds is offshore in the Gulf of St. Lawrence. The distribution of Upper Devonian to Permian rocks of the Maritimes Basin is shown in Figure 1. Figure 2 is a more detailed map showing the distribution of Upper Devonian and Carboniferous rocks in southeast New Brunswick. The study area is located immediately to the north and east of the town of Sussex. A geological map of the study area is provided in Plate 1. Crystalline

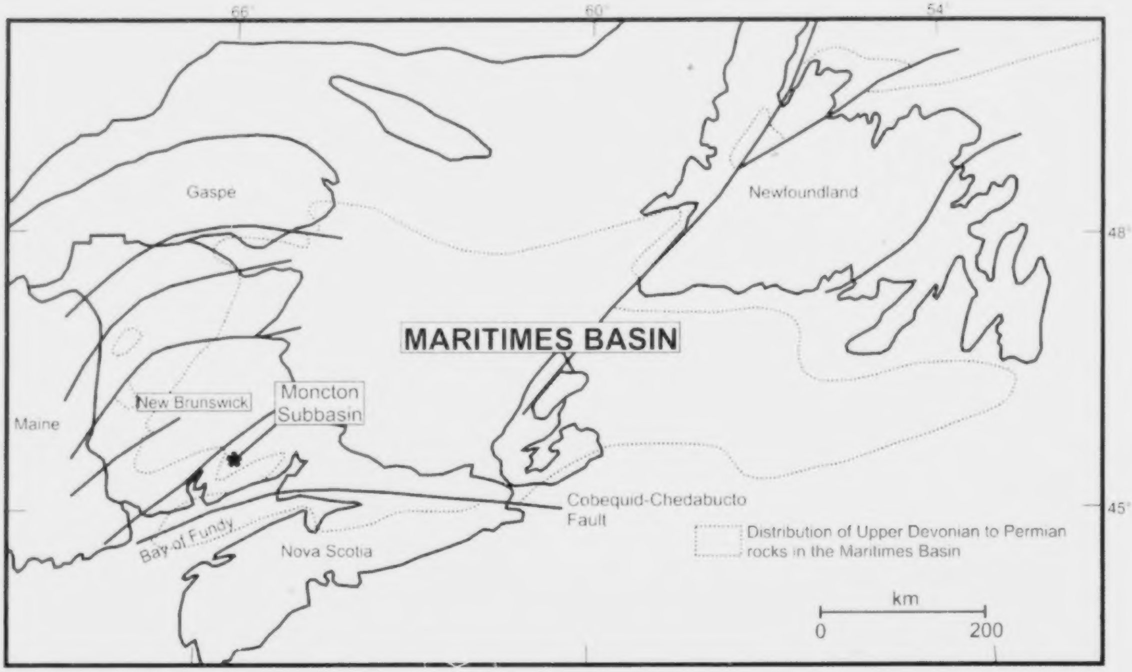


Figure 1. Regional distribution of the Maritimes Basin. Redrawn after Martel (1987).

basement is exposed in the southeast part of the study area (the Caledonia Uplift, Figure 2; Plate 1) and in a fault block at Jordan Mountain in the northwest. Upper Devonian and Lower Carboniferous rocks of the Horton, Moncton, and Windsor groups are exposed in the south of the area and to the northwest of the Berry Mills Fault. The central part of the area is underlain by Upper Carboniferous rocks of the Mabou, Cumberland, and Pictou groups. These rocks lie in a synclinorium, which is bifurcated by a narrow, northeast-trending salt-cored anticline. The area is cut by a number of important northeast- or east-trending faults, including the Berry Mills, Penobsquis, Gordon Falls, and Clover Hill faults. The area is of economic importance because of the presence of rock salt and potash deposits in the Viséan Cassidy Lake Formation (Windsor Group) and the presence of a petroleum system in the Tournaisian Albert Formation (Horton Group).

Hydrocarbon exploitation in the Moncton Subbasin of New Brunswick has had a long history. A vein of albertite (a solid form of bitumen) was mined at Albert Mines south of Hillsborough (Figure 2) between 1850 and 1876 (Williams 1974). Drilling for oil and gas began in 1858 near Moncton, and small quantities of oil and gas were produced from the Dover area in the early years of the 20th century (Roliff 1955; Williams 1974). The Stoney Creek field, approximately 15 km south of Moncton on the west side of the Petitcodiac River (Foley 1989; Figure 2), was discovered in 1909. Around 800 000 barrels of paraffinic oil and 30 billion cubic feet (bcf) of sweet gas were produced from the Stoney Creek field between the years of 1910 and 1991, when the field ceased production (St. Peter 2001). More recent hydrocarbon exploration in the Moncton Subbasin has concentrated on the Hillsborough area (straddling the Petitcodiac River approximately 25 km south of Moncton; Wilson 2002) and the McCully gas field near Sussex. Estimates suggest that there are at least 500 bcf of gas in place in the McCully field (Durling and Martel 2003). The McCully 1 and 2 wells began gas production to supply

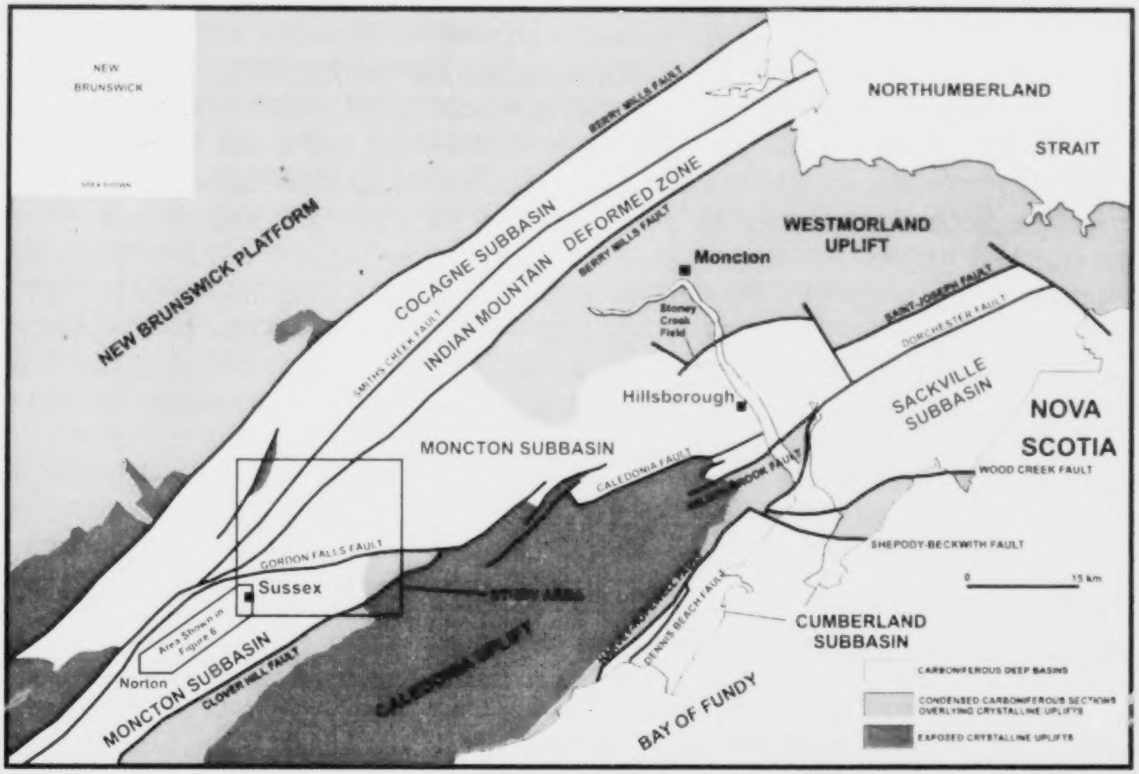

NEW
BRUNSWICK
AREA SHOWN
NEW BRUNSWICK PLATFORM
COCAGNE SUBBASIN
INDIAN MOUNTAIN DEFORMED ZONE
SMITHS CREEK FAULT
BERRY MILLS FAULT
BERRY MILLS FAULT
NORTHUMBERLAND
STRAIT
WESTMORLAND
UPLIFT
Moncton
Stoney
Creek
Field
SAINT-JOSEPH FAULT
DORCHESTER FAULT
Hillsborough
SACKVILLE
SUBBASIN
NOVA
SCOTIA
MONCTON SUBBASIN
CALEDONIA FAULT
WOOD CREEK FAULT
SHEPODY-BECKWITH FAULT
GORDON FALLS FAULT
Sussex
STUDY AREA
0
15 km
Area Shown in
Figure 6
Norton
MONCTON SUBBASIN
CLOVER HILL FAULT
CALEDONIA UPLIFT
DENNIS BEACH FAULT
CUMBERLAND
SUBBASIN
BAY OF FUNDY
CARBONIFEROUS DEEP BASINS
CONDENSED CARBONIFEROUS SECTIONS
OVERLYING CRYSTALLINE UPLIFTS
EXPOSED CRYSTALLINE UPLIFTS

Figure 2. Map of the Maritimes Basin in southeast New Brunswick, showing the major faults.

the PCS mill at the Penobsquis potash mine in April 2003, and exploration efforts in the study area are continuing.

The exploitation of salt and potash deposits in the study area also has a long history. Between 1850 and 1900 production of salt in the area relied on evaporation of brines from salt springs at Plumweseep (Hamilton 1961). Gussow (1953) noted a linear gravity anomaly extending 20 km between Plumweseep and Portage Vale (Plate 1). Gussow also noted salt springs and sinkholes in the area, and suggested that the gravity anomaly might result from the presence of a near-surface salt body. The presence of salt and potash in the subsurface was confirmed by the New Brunswick Department of Natural Resources Plumweseep 1 and Penobsquis 1 boreholes (Plate 1 for locations) in 1971 (Howie 1988). Both holes intersected significant thicknesses of high-purity rock salt, and Plumweseep 1 also intersected significant potash (Howie 1988). The Potash Company of America began an exploration program in 1973, which led to the opening of the Penobsquis mine in 1983. The mine is now operated by the Potash Corporation of Saskatchewan Inc. (PCS). The company initiated a new potash exploration program in the study area in 2002, discovering a new potash deposit to the southeast of the main salt structure.

Despite its economic potential, the tectonic evolution of the Moncton Subbasin is incompletely understood. The main structural control is provided by northeast- to east-trending faults, many of which are inherited Acadian structures that have experienced numerous periods of reactivation.

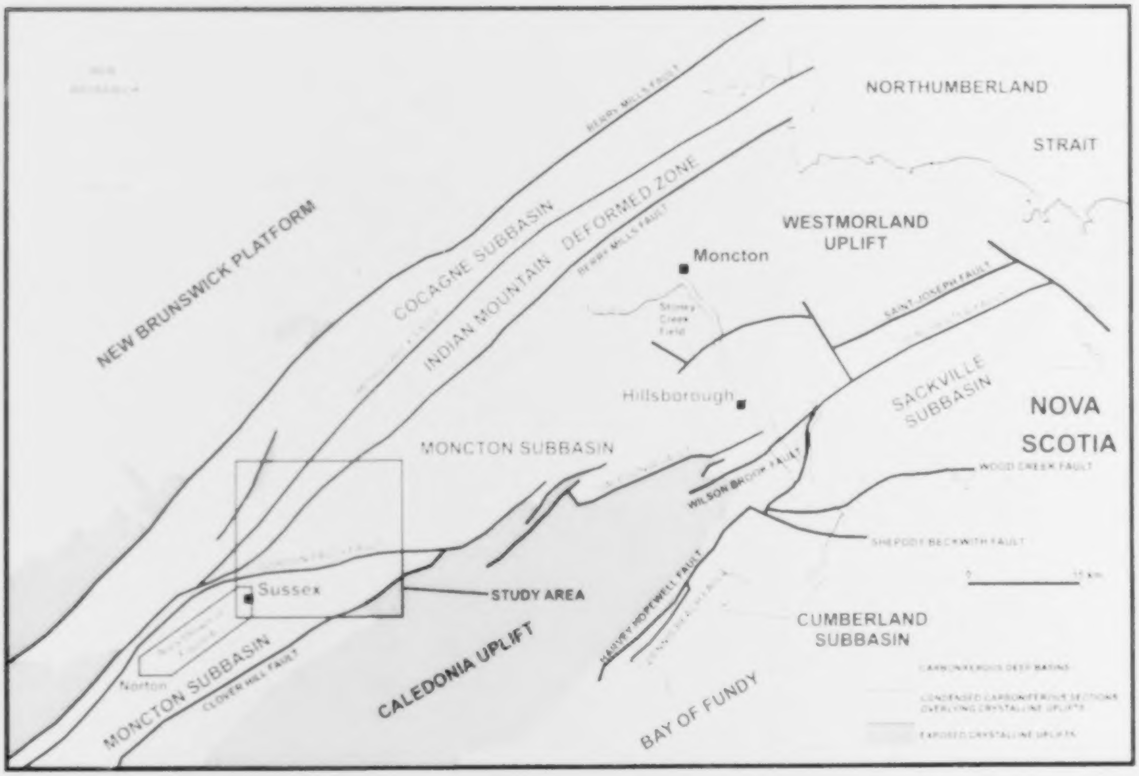

NEW BRUNSWICK PLATFORM
COCAGNE SUBBASIN
INDIAN MOUNTAIN DEFORMED ZONE
BERRY MILLS FAULT
BERRY MILLS FAULT
NORTHUMBERLAND
STRAIT
WESTMORLAND
UPLIFT
Moncton
Stoney Creek Field
SAINT-JOSEPH FAULT
Hillsborough
SACKVILLE
SUBBASIN
NOVA
SCOTIA
MONCTON SUBBASIN
WILSON BROOK FAULT
WOOD CREEK FAULT
SHEPODY BECKWITH FAULT
0
15 km
Sussex
STUDY AREA
HARVEY HOPEWELL FAULT
CUMBERLAND
SUBBASIN
Norton
MONCTON SUBBASIN
CLOVER HILL FAULT
CALEDONIA UPLIFT
BAY OF FUNDY
CARBONIFEROUS DEEP BASINS
CONDENSED CARBONIFEROUS SECTIONS OVERLYING CRYSTALLINE UPLIFTS
EXPOSED CRYSTALLINE UPLIFTS

Figure 2. Map of the Maritimes Basin in southeast New Brunswick, showing the major faults.

the PCS mill at the Penobsquis potash mine in April 2003, and exploration efforts in the study area are continuing.

The exploitation of salt and potash deposits in the study area also has a long history. Between 1850 and 1900 production of salt in the area relied on evaporation of brines from salt springs at Plumweseep (Hamilton 1961). Gussow (1953) noted a linear gravity anomaly extending 20 km between Plumweseep and Portage Vale (Plate 1). Gussow also noted salt springs and sinkholes in the area, and suggested that the gravity anomaly might result from the presence of a near-surface salt body. The presence of salt and potash in the subsurface was confirmed by the New Brunswick Department of Natural Resources Plumweseep 1 and Penobsquis 1 boreholes (Plate 1 for locations) in 1971 (Howie 1988). Both holes intersected significant thicknesses of high-purity rock salt, and Plumweseep 1 also intersected significant potash (Howie 1988). The Potash Company of America began an exploration program in 1973, which led to the opening of the Penobsquis mine in 1983. The mine is now operated by the Potash Corporation of Saskatchewan Inc. (PCS). The company initiated a new potash exploration program in the study area in 2002, discovering a new potash deposit to the southeast of the main salt structure.

Despite its economic potential, the tectonic evolution of the Moncton Subbasin is incompletely understood. The main structural control is provided by northeast- to east-trending faults, many of which are inherited Acadian structures that have experienced numerous periods of reactivation.

There has been some controversy as to the relative importance of dip-slip and strike-slip movements on these faults (e.g., Gussow 1953; Garnett and Brown 1973; Bradley 1982; Ruitenberg and McCutcheon 1982; Leger and Williams 1986; McCutcheon and Robinson 1987; St. Peter 1992, 1993; Nickerson 1994; Wilson 2002). Salt flow has contributed to deformation in some parts of the Maritimes Basin, including the area of this study, but the timing and causes of this are not well understood. The protracted and complex tectonic history of the Moncton Subbasin has led to rapid internal facies variations within some rock units, notably the lacustrine hydrocarbon-bearing Albert Formation (Greiner 1962, 1974; Macauley et al. 1984; Carter and Pickerill 1985a, 1985b; St. Peter 1992, 1993; van de Poll 1995). This, coupled with the generally poor exposure, has hindered a clear understanding of the structural and tectonic history of the area, and in particular the identification of hydrocarbon prospects in the Moncton Subbasin. New seismic and borehole data related to local potash and hydrocarbon exploration allow a re-evaluation of the structural geology and tectonic history of the area.

PROJECT METHODOLOGY

Selected field transects were undertaken in the map area (Plate 1) during the 2002 and 2003 field seasons. Field mapping concentrated on areas where interpretations of borehole and seismic data suggest complexity or ambiguity of interpretation. Detailed structural work was undertaken on exposures of the Albert Formation along New Brunswick Highway 1, which provide the best exposed section of Albert Formation rocks in the study area. Access to proprietary borehole and seismic data was granted by PCS and Corridor Resources Inc. for the purposes of this study. Cores from mineral exploration boreholes drilled in the study area were examined and the structural features therein recorded. Of these boreholes, four were drilled by the New Brunswick Department of Natural Resources; thirty-five were drilled by the Potash Company of America (PCA) in the middle to late 1970s; and a further five were drilled by PCS in 2002. The locations of the boreholes are shown in Plate 1. Industry-generated seismic reflection profiles provided by PCS and Corridor Resources Inc. were interpreted. Six new seismic reflection profiles and two reprocessed public-domain seismic reflection profiles were provided by Corridor Resources Inc. Four additional profiles acquired by PCS for potash exploration were also provided. All seismic profiles were converted from two-way time to depth. The profiles form a grid, with ten NW–SE trending profiles and two NE–SW trending profiles. The locations of the profiles are shown in Plate 1. Borehole control (Plate 1) is provided by PCS/Corridor McCully 1 and 2, Corridor/PCS McCully P–56 and C–75, and EOG/Corridor McCully D–48, H–28 and J–65, all of which were completed in the Albert Formation. Additional control on evaporite stratigraphy and structure is provided by PCA and PCS mineral exploration coreholes. A review of the pertinent literature, published maps, available cores, cuttings and wireline logs was also undertaken.

LITHOSTRATIGRAPHY

INTRODUCTION

The Pre-Windsor section in the Moncton Subbasin has traditionally been assigned to the Horton Group, comprising in ascending order the Memramcook, Albert, and Weldon formations. The Horton strata have until recently been interpreted to be unconformably overlain by the polymictic conglomerates of the Hillsborough Formation (Gussow 1953; St. Peter 1992, 1993). Norman (1941a, 1941b) included the Hillsborough and Weldon formations in the Moncton Group. Gussow (1953) retained this usage, despite recognizing an unconformity between the Weldon and Hillsborough formations. Carter and Pickerill (1985b) recommended that the Weldon and Hillsborough formations be reduced to member status within the Moncton Formation, and that the Horton/Windsor boundary be placed at the base of the first marine bed (i.e., above the Hillsborough Formation), as in the original definition of those groups (Bell 1929). The contact between the Weldon and Hillsborough formations was defined as an unconformity in some areas (e.g., Hillsborough) and as a conformable contact in other areas (e.g., Sussex). More recent stratigraphic schemes (St. Peter 1992, 1993, 2001) have placed the Hillsborough Formation at the base of the Windsor Group, and the Weldon Formation at the top of Horton Group, abandoning the name Moncton entirely. McLeod (1980) additionally included the Round Hill Formation in the Horton Group. The Round Hill Formation consists of the grey polymictic cobble and boulder conglomerates that outcrop along the northern margin of the Caledonia Uplift in the eastern part of the Moncton Subbasin near Hillsborough. The Round Hill was defined as gradational with the overlying Weldon Formation, and as a facies equivalent of all or part of the Albert Formation (McLeod 1980). Later workers reduced this unit to member status within the Albert Formation, as the proximal coarse-grained equivalent of the distal Albert facies (Macauley et al. 1984; Carter and Pickerill 1985b).

New mapping and interpretation of new industry-generated deep boreholes and seismic reflection profiles in the western Moncton Subbasin (St. Peter 2002; Keighley 2004; this study) show that revisions to the pre-Windsor stratigraphy are required. Seismic profiles clearly show that the Horton Group is unconformably overlain by a sequence of terrestrial clastics that lie below the marine Windsor Group. The sequence consists of three conformable units; they are, in order of younging, a basal red and grey polymictic conglomerate unit; a medial fine-grained redbed unit; and an upper grey, yellow-grey and red polymictic conglomerate unit, the latter corresponding to the Hillsborough Formation. It is suggested that the name "Moncton Group" be reinstated to include the three mutually conformable units which unconformably overlie the Horton Group and conformably underlie the marine beds of the Windsor Group. In a previous interpretation (Wilson 2003), this sequence was given the name "Sussex Group", with the basal conglomerate unit referred to as the Mill Brook Formation and the medial fine-grained redbed unit referred to as the Dutch Valley Formation. This usage was adopted because the medial redbed unit rests unconformably on the Horton Group in the McCully gas field area. It was therefore not considered stratigraphically equivalent to the Weldon Formation, which has always been defined as conformable on the Albert Formation (Norman 1941a, 1941b; Gussow 1953; Carter and Pickerill 1985a; St. Peter 1992, 1993). However, recent spore dates and bedrock mapping in the Hillsborough area indicate that the type Weldon Formation at Weldon Creek (in the sense of Norman 1941b) does in fact lie unconformably on the Horton Group, and that therefore the medial redbed unit in the McCully and Sussex areas does correspond to the Weldon Formation (St. Peter, personal communication, 2004). The basal conglomerate unit of Norman's (1941b) Weldon Formation, which is recognized in the McCully area, corresponds to the Round Hill Formation of McLeod (1980). Therefore the Round Hill Formation is assigned as the basal unit of the Moncton Group. It lies unconformably on the Horton Group, and is conformably succeeded by the Weldon Formation.

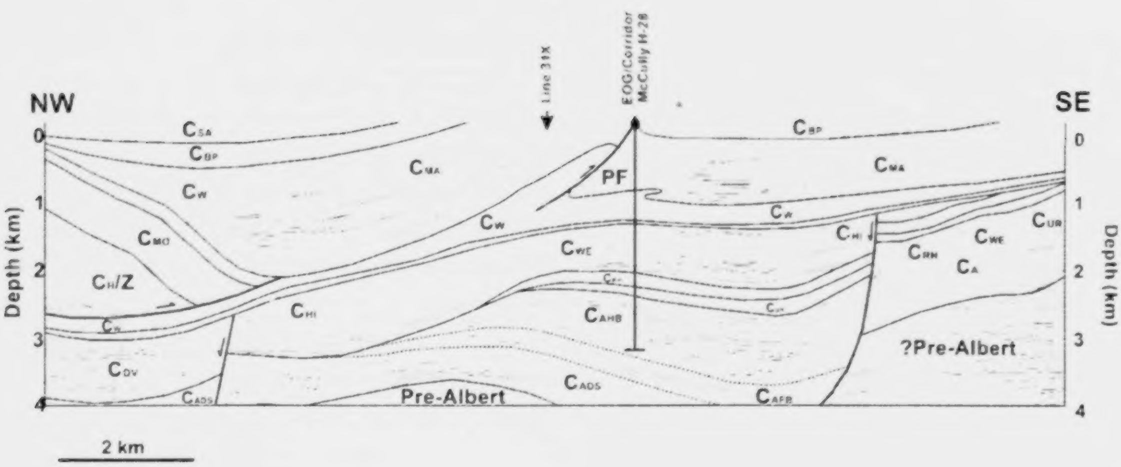


Figure 3. Interpretation of seismic line 6.

In the H–28 borehole (Plate 1; Figure 3), Albert Formation rocks are conformably overlain by a unit of fine-grained redbeds, consisting of approximately 100 m of red claystone, shale, siltstone, and fine sandstone. This redbed unit within the Horton Group requires a new name. The unit will not be named formally in this report as an appropriate surface type section has not yet been identified; it will be referred to informally as the "unnamed redbed" formation.

The lithostratigraphy of the Moncton Subbasin based on these revisions is shown in Table 1.

BASEMENT COMPLEX

Rocks of the basement complex of the Caledonia Uplift (Figure 2) outcrop to the southeast of the Clover Hill Fault, in the Jordan Mountain uplift in the northwest of the study area, and in a fault-bounded sliver along the Clover Hill Fault near Cedar Camp (Plate 1, back pocket). The basement complex consists of Proterozoic to Middle Devonian metasedimentary, metavolcanic, and igneous rocks that underlie the Late Devonian-Carboniferous sedimentary rocks of the Maritimes Basin. Basement rocks in southern New Brunswick are assigned to the Avalon Zone of the Appalachian orogen (Williams 1979). More recently, workers have divided the Avalon Zone into several peri-Gondwanan terranes (e.g., Barr and White 1996, and references therein).

HORTON GROUP

The Horton Group is the basal stratigraphic group of the Moncton Subbasin. It consists of the conformable Memramcook, Albert, and "unnamed redbed" formations. The Memramcook Formation is exposed in the northwest of the study area (Plate 1). It consists of purple-red polymictic conglomerates with hematite-coated clasts, arkosic sandstones, and minor red mudstones. It is thought to be late Devonian in age because it is overlain by the earliest Carboniferous Albert Formation and because it contains late Devonian miospores in the type section at Stoney Creek, southeast of Moncton (Carr 1968).

Table 1. Table of formations for the western Moncton Subbasin.

SYSTEM	SERIES		GROUP	FORMATION	LITHOLOGY
UPPER CARBONIFEROUS	WESTPHALIAN	D	PICTOU		
		C		SALISBURY	Red mudstones, siltstones, sandstones and conglomerates; minor thin coal seams
		B			
		A	CUMBERLAND	BOSS POINT	Yellow-grey quartzose sandstone and quartz-pebble conglomerate; minor red sandstone, grey and red mudstone, thin coal seams
	NAMURIAN	C			
		B			
		A			
LOWER CARBONIFEROUS	VISEAN		MABOU	UNDIVIDED UNITS	Red to grey polymictic pebble and cobble conglomerate; minor red sandstone, siltstone and mudstone.
			WINDSOR	CLOVER HILL	Halite, argillaceous halite, anhdrite and claystone
				CASSIDY LAKE	Halite, argillaceous halite, sylvinite and anhydrite
				UPPERTON	Anhydrite and gypsum
				MACUMBER/ GAYS RIVER	Wackestone, packstone, algal boundstone; minor floatstone and intraformational breccia
			MONCTON	HILLSBOROUGH	Yellow-grey to red polymictic conglomerate and sandstone; minor red mudstone
	TOURNAISIAN			WELDON	Red mudstone, siltstone and fine sandstone; minor grit and polymictic conglomerate
				ROUND HILL	Grey polymictic conglomerate, grit and coarse sandstone
				HAZEL HILL MEMBER	HAZEL HILL: Grey conglomerate containing green-grey chert and marble clasts.
			HORTON	'UNNAMED REDBED'	Red mudstone, siltstone and fine sandstone; minor grit and polymictic conglomerate
				ALBERT	Mostly grey feldspathic sandstone, mudstone, kerogeneous mudstone and shale, polymictic conglomerate; minor limestone.
				MEMRAMCOOK	Red to grey polymictic boulder conglomerates with minor sandstone and mudstone
UPPER DEVONIAN					
MID. DEVONIAN AND OLDER			BASEMENT COMPLEX		

The Early to Middle Tournaisian Albert Formation consists of alluvial, fluvial, and lacustrine sediments (St. Peter 1992). It is economically important because it contains a petroleum system. The Albert Formation consists of four members which have complex lithofacies relationships (Greiner 1974; Macauley et al. 1984; Carter and Pickerill 1985a, 1985b; van de Poll 1995); the Dawson Settlement, Frederick Brook, Hiram Brook, and Gautreau members. The Dawson Settlement Member consists mainly of coarse- to fine-grained sandstone with intercalations of shale and conglomerate; the Frederick Brook Member consists of kerogeneous shale, kerogeneous mudstone, siltstone, and minor sandstone and conglomerate; and the Hiram Brook Member consists of kerogeneous and calcareous siltstone, shale, sandstone, and minor conglomerate. In the southeastern Moncton Subbasin, the Gautreau Member (Carter and Pickerill 1985b) comprises lacustrine evaporite deposits and shale, thought to represent a salt-flat facies deposited during the drying up of Lake Albert (St. Peter 1992). The Gautreau Member is laterally equivalent to the Hiram Brook member. Although no Albert salt has been intersected in boreholes in the study area, about 108 m of rock salt and glauberite was intersected in the Province of New Brunswick Cornhill 3 borehole, just to the north of the study area (Howie 1988; St. Peter 1992). Thick intervals of polymictic conglomerate are present in the Dawson Settlement, Frederick Brook, and Hiram Brook members of the Albert Formation adjacent to the Caledonia Uplift (McCutcheon 1978; St. Peter 1992, 1993). The conglomerates are interpreted as proximal alluvial fan facies and are equivalent to the finer grained basin-centre facies of the Albert Formation encountered in the gas exploration wells in the McCully field.

The "unnamed redbed" formation consists of red mudstone, siltstone, and shale. The "unnamed redbed" formation has been cut out by the post-Horton/pre-Moncton unconformity over much of the study area, and is not present at the surface. However, it is present in the subsurface; for example in the H–28, P–56, and C–75 wells (Plate 1) fine-grained redbeds are unconformably overlain by rocks of the Moncton Group.

MONCTON GROUP

The Moncton Group consists of the Round Hill (including the Hazel Hill Member), Weldon, and Hillsborough formations. There may be minor time gaps between these formations, but they are structurally conformable.

The Round Hill Formation outcrops principally in the south of the study area around Urney and Cedar Camp (Plate 1). The most complete section is preserved along Mill Brook. It unconformably overlies the "unnamed redbed" and Albert Formation, and consists of grey-green to reddish polymictic conglomerates, lithic microconglomerates, lithic sandstones, and minor mudstones. Along Highway No. 1 just west of Sussex (see below under structural geology of the Albert Formation) a distinctive chert-clast conglomerate can be seen disconformably overlying shales of the Albert Formation; this is the Hazel Hill Member of the Round Hill Formation (St. Peter 2002). In seismic reflection profiles the Round Hill Formation has a variable thickness of 50–200 m; it is thickest in the Mill Brook area (Plate 1; St. Peter 1995).

The Weldon Formation outcrops in the south of the study area in the valley of Trout Creek and immediately to the northwest of the Berry Mills Fault (Plate 1). It consists mostly of red and locally grey mudstone, siltstone, and fine sandstone; however, grit and polymictic conglomerate are locally present. It conformably overlies the Round Hill Formation. Seismic interpretations and well intersections suggest that the unit has a thickness of around 800 m in the McCully gas field area and thins toward the Clover Hill Fault in the southeast (e.g., Plate 1; Figure 3).

The Hillsborough Formation outcrops along a prominent ridge between Picadilly and Urney, as well as on the south side of Jordan Mountain in the northwest of the study area (Plate 1). The Hillsborough Formation consists of grey or red polymictic conglomerates and coarse lithic sandstones. It conformably overlies the Weldon Formation and is overlain with structural conformity by the marine rocks of the Windsor Group.

WINDSOR GROUP

In the Sussex area, the Windsor Group consists largely of marine evaporites. A detailed report on the Windsor Group stratigraphy was produced by McCutcheon (1981) and much of the following is derived from his work. The stratigraphy of the Windsor Group is outlined in Table 2.

The Macumber Formation consists of sparsely fossiliferous, thinly bedded to finely laminated, grey limestone. It has a distinct petroliferous odour when freshly broken. The unit is thin, varying between approximately 10 and 50 m in thickness, but has a large areal coverage, being deposited over much of the Maritimes Basin (McCutcheon 1981). It is a good time marker, representing the initial marine transgression. The unit outcrops extensively, forming a narrow upstanding ridge in many areas. The Gays River Formation is in part the lateral (landward) equivalent of the Macumber Formation. It consists of laminated to thick-bedded algal boundstone and a basal bafflestone.

The Upperton Formation consists of "stratiform, replacive and displacive, nodular to mosaic anhydrite" (McCutcheon 1981). Exposed sections have generally undergone some degree of gypsification. The unit is present across much of the basin. It is a recessive unit and does not provide many outcrops, but its surface distribution can be inferred from the presence of karst topography. In boreholes it tends to be steel-blue to dark grey in colour, and fine grained to cryptocrystalline.

The Cassidy Lake Formation overlies the Upperton Formation and consists largely of rock salt and potash. It does not outcrop, existing only in the subsurface. The Cassidy Lake Formation is the source of potash deposits currently being mined by PCS. The unit has been subdivided into four informal members (Table 2) based on mine geology and borehole data (Geldsetzer 1978; Kingston and Dickie 1979; Anderle et al. 1979; Roulston and Waugh 1985; Howie 1988). The lowermost basal halite member consists of clean to anhydritic coarsely crystalline halite. The overlying middle halite unit consists of argillaceous halite, and is subdivided into a lower grey-green unit and an upper red-brown unit. The middle halite is overlain by the ore zone which consists of sylvinite grading 10–40% KCl. The ore zone has a basal lower gradational zone consisting of pale orange halite with fine crystals of sylvite that increase in concentration upward. The highly heterogeneous upper halite unit is the topmost unit of the Cassidy Lake, and has been divided into four subunits. The basal unit ("banded") consists of broad 10 cm to 1 m thick bands of clean crystalline orange halite, red-purple argillaceous halite, and sylvinitic argillaceous halite. The "sylvinite" unit comprises sylvinite with an

Table 2. Stratigraphy of the Windsor Group in the western Moncton Subbasin.

GROUP	FORMATION	MEMBER		LITHOLOGY
MABOU	Undivided Units			Red to grey polymictic pebble and cobble conglomerate; red and minor green mudstone and sandstone
WINDSOR	Clover Hill	Penobsquis Salt		Coarse crystalline, clean to argillaceous, grey to pale orange halite.
		Upper Anhydrite		Fine-grained to cryptocrystalline, dark grey-blue massive anhydrite.
	Cassidy Lake	Upper Halite	Coarse	Coarse, clean to argillaceous transparent, grey and pale orange halite.
			Finely Laminated	Red-purple argillaceous halite and sylvinite with mm-scale laminae of grey-green clay.
			Sylvinite	Low-grade sylvinite; carnallite in the northeast.
			Banded	Broad (10s cm) bands of coarse, clean translucent to pale orange halite, red-purple argillaceous and sylvitic halite, and sylvinite.
		Ore Zone		Sylvinite at KCL grades up to ~40%; usually associated with medium to coarse crystalline pale grey halite, traces of blue halite and disseminated grey-green or red-brown clay.
		Middle Halite	Red-brown	Red-brown argillaceous halite
			Grey-green	Grey-green argillaceous halite
		Basal Halite		Coarse, transparent to dark grey, clean to anhydritic halite.
	Upperton			Fine-grained to cryptocrystalline dark grey-blue massive to finely laminated anhydrite.
	Macumber			Thinly bedded to laminated, dark grey, sparsely fossiliferous limestone.
MONCTON	Hillsborough			Yellow-grey to red polymictic conglomerate and lithic sandstone; minor red mudstone.

average sylvite grade of around 15%. Carnallite is found in this unit in some boreholes, especially toward the northeast of the study area. The "finely laminated" unit consists of deep red-orange clean halite and low-grade sylvinite bands on the order of 510 cm thick, separated by mm-scale laminae of grey-green clay. It contains numerous borate minerals as scattered platy crystals and spheroidal aggregates (Roulston and Waugh 1981). The topmost "coarse" subunit consists of coarse to very coarse dark grey and orange argillaceous halite. Near the crest of the main salt ridge, dissolution of salt and collapse of overlying rocks have formed solution-collapse breccia, consisting of angular to rounded fragments of anhydrite and green or red mudstone in a green or red muddy matrix. Such breccias are referred to as the "cap rock" in the mine stratigraphy. In some boreholes (e.g., D–2A, D–

4; see Plate 1 for locations), the cap rock lies directly on the basal halite, showing that a significant section has been removed by dissolution.

In the study area, the Cassidy Lake Formation is overlain by the Clover Hill Formation. The Clover Hill is confined to the subsurface. It consists of a basal dark grey-blue fine-grained crystalline anhydrite unit (referred to as the "upper anhydrite" in the mine stratigraphy) and an upper dark grey and pale orange, coarse, argillaceous halite unit (referred to as "Penobsquis salt").

The upper contact of the Windsor Group is problematic. McCutcheon (1981) noted that the top of the Windsor has a weathered appearance in some areas, concluding that there was a significant hiatus between Windsor and Mabou deposition. Aerial photographs also show an angular discordance between Hillsborough Formation and Mabou Group bedding ridges (McCutcheon 1981). In the basin centre, seismic profiles show that the contact is structurally conformable (e.g., Figure 3), and borehole evidence suggests a gradational contact between argillaceous halite and marine clay of the Clover Hill Formation and mudstone and sandstone of the Mabou Group. At the basin margins, Mabou Group rocks are observed to step across the Windsor Group stratigraphy onto basement. In some areas at the basin margin the contact may be defined by salt welds. A salt weld is defined as "a surface across which now-adjacent strata were originally separated by salt that is now depleted or absent" (Giles and Lawton 1999). Where the contact has been modified by salt tectonics in the centre of the basin, the contact may be intrusive (see below under structural geology of the Windsor Group). The evidence suggests that the Windsor/Mabou contact is an unconformity or salt weld at the basin margins, and conformable or intrusive in the basin centre.

MABOU GROUP

In the central part of the study area, evidence from mineral exploration boreholes shows that the Late Viséan to Namurian A Mabou Group comprises a lower fine-grained unit consisting mainly of red mudstone and sandstone, and an upper coarse-grained unit consisting largely of polymictic conglomerate (Anderle et al. 1979; McCutcheon 1981). The conglomerates contain extra-basinal clasts derived from basement lithologies. Mapping in the Mount Pisgah area shows that the coarse-grained unit is overlain by a unit of brick-red micaceous siltstone and fine sandstone. The Mabou Group units recognized at Mount Pisgah may correspond to the Poodiac, Wanamaker, and Scoodic Brook formations recognized in the Salt Springs area (Anderle et al. 1979). For the purposes of this study the Mabou Group is treated as undivided. The Mabou Group is separated from overlying Cumberland Group rocks by a major unconformity (e.g., Gussow 1953; St. Peter 1992, 1993).

CUMBERLAND AND PICTOU GROUPS

In the study area, the Cumberland Group consists of yellow-grey sandstones, microconglomerates, quartz-pebble conglomerates, and thin coal seams of the Boss Point Formation. The Boss Point Formation outcrops in the east and northeast of the study area, and is of Late Namurian to Westphalian A age (Johnson 1995). The Cumberland Group in southeastern New Brunswick is paraconformably overlain by the Pictou Group. Fluvial grey sandstones and grey to red mudstones of the Westphalian C-age Salisbury Formation are the only Pictou Group unit exposed in the study area.

STRUCTURAL GEOLOGY

STRUCTURAL GEOLOGY OF THE ALBERT FORMATION

Structure of the McCully gas field

A brief summary of the geology of the McCully gas field is available in Durling and Martel (2003). In the McCully area the Albert Formation occupies a half-graben bounded to the southeast by the Clover Hill Fault. On seismic line 5 (Figure 4), Albert Formation and Moncton Group rocks in the hanging wall are juxtaposed against basement overlain by Moncton Group rocks in the footwall, indicating normal-sense movement on the Clover Hill Fault prior to Moncton Group deposition. The Albert Formation has a total thickness of approximately 1700 to 2000 m in the centre of the study area. Seismic interpretation suggests that the Albert is thinner (approximately 1200 m) to the south of the Gordon Falls Fault, and that no Albert exists to the southeast of the Clover Hill Fault. The Albert Formation is progressively cut out to the northwest by the pre-Moncton unconformity (Figures 3 and 4).

The reservoir interval occurs within the sands of the Hiram Brook Member, which is between 400 to 800 m thick. The Hiram Brook comprises grey shale and fine- to medium-grained sandstones. There are five sand packages with gross thicknesses of between 40 and 60 m; porosity in the reservoir ranges from 6 to 10% and permeability is less than 2 millidarcies (Durling and Martel 2003). Hence volumes of potential elevated permeability would be important exploration targets (see below under structural geology of the Windsor Group).

Near to the McCully 1 well, the Albert Formation lies in a northeast-trending, doubly plunging anticline about 12 km long and 5 km wide. The anticlinal structure is truncated by the pre-Moncton Group regional unconformity, which is immediately overlain by impermeable polymictic pebble and cobble conglomerates of the Round Hill Formation. The trap may therefore be a combined anticline and unconformity trap. The role of faults in trapping gas at McCully is not completely understood, but seismic interpretations (Figure 5) suggest that there are a number of thrust faults within the Albert Formation in the McCully gas field. Field observations show that the Albert Formation southwest of the study area is cut by numerous normal faults. It is possible that faults in the gas field assist trapping, either through juxtaposition of impermeable layers against reservoir, or through emplacement of impermeable fault zone material due to mechanical or chemical processes related to faulting (Hubbert 1953; Smith 1966, 1980; Knipe 1992). See further below under Discussion.

Surface structural geology of the Albert Formation

Albert Formation rocks are best exposed in the Urney and Cedar Camp areas (Plate 1) and along Highway 1 between Sussex and Norton (Figure 2). The highway outcrops are outside the formal study area, but provide useful insights into the structural geology of the Albert Formation, especially given the lack of exposure of the Albert Formation within the study area. Seven highway outcrops were studied (Figure 6). Synoptic diagrams of the orientations of structural features are displayed in Figure 7. In general, the structural geology becomes more complex toward the southwest, as the Kennebecasis River Fault is approached.

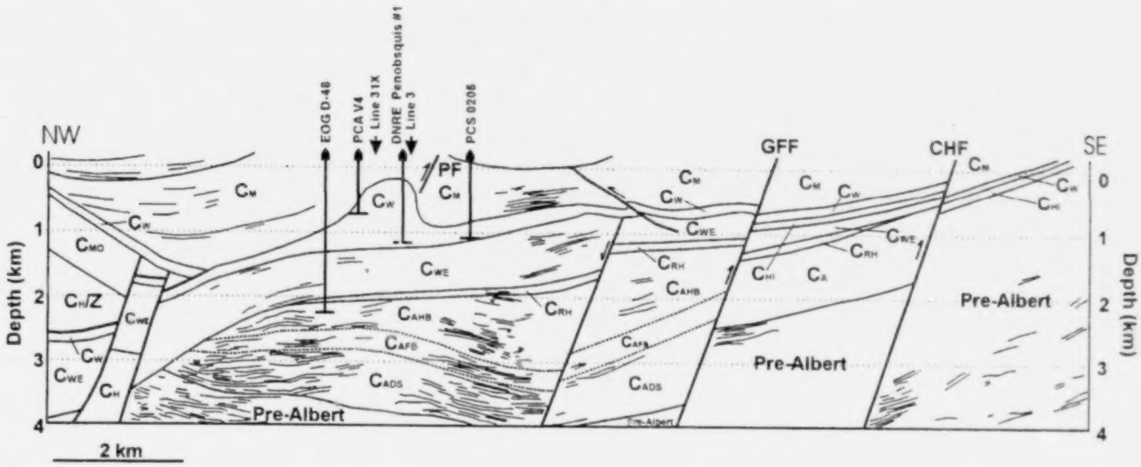


Figure 4. Interpretation of seismic line 5.

In the Urney and Cedar Camp areas, the Albert Formation is exposed along Cedar Camp Brook between Cedar Camp and Waterford, and also in the core of the Urney anticline. Along Cedar Camp Brook the main structure is a northeast-trending, doubly plunging, upright anticline (Plate 1). The Urney anticline is northeast trending and asymmetric, with the southeast-dipping limb much steeper than the northwest-dipping limb (Plate 1). This fold may be related to a northeast-trending, southeast-directed thrust fault.

At outcrop 1 on Hwy. 1 (Figure 6), dark grey to black shales of the Albert Formation are overlain with structural conformity by the Hazel Hill Member of the Round Hill Formation (Figure 8a). The presence of a soil horizon at the top of the Albert Formation suggests a time gap. The structure is simple, with the beds monoclinally dipping toward the north. Outcrops in this area are cut by minor dip-slip faults with small displacements.

To the southwest (outcrops 2 and 3) gently east-dipping Albert Formation shales, mudstones, and fine- to medium-grained sandstones are exposed. The rocks are folded around a kilometre-scale, non-plunging, upright, anticline, The west-dipping limb of the anticline lies southwest of outcrop 4. Further to the southwest, bedding steepens and the strike swings around to the northeast (outcrop 5), reflecting rotation by the Kennebecasis River Fault which lies to the northwest. Gently south-plunging, tight, recumbent folds are observed at the southwest end of outcrop 5 (Figure 8b). The hinges of the folds are broken (Figure 8c). The folded section is separated from the unfolded section to the northeast by a minor east-trending fault. The sense of drag folding by the fault indicates that it is a dextral strike-slip fault. Steeply dipping, northeast-striking, northwest-younging rippled sandstones are juxtaposed against steeply dipping, northeast-striking southeast-younging rippled sandstones across a north-trending fault at the northeast end of outcrop 6. The sense of drag folding indicates sinistral displacement. These observations are explained as a result of the juxtaposition of northwest-younging and southeast younging limbs of northeast-trending tight folds by the cross-cutting strike-slip fault. Further to the southwest at outcrop 6, the rocks are cut by a northeast-trending fault

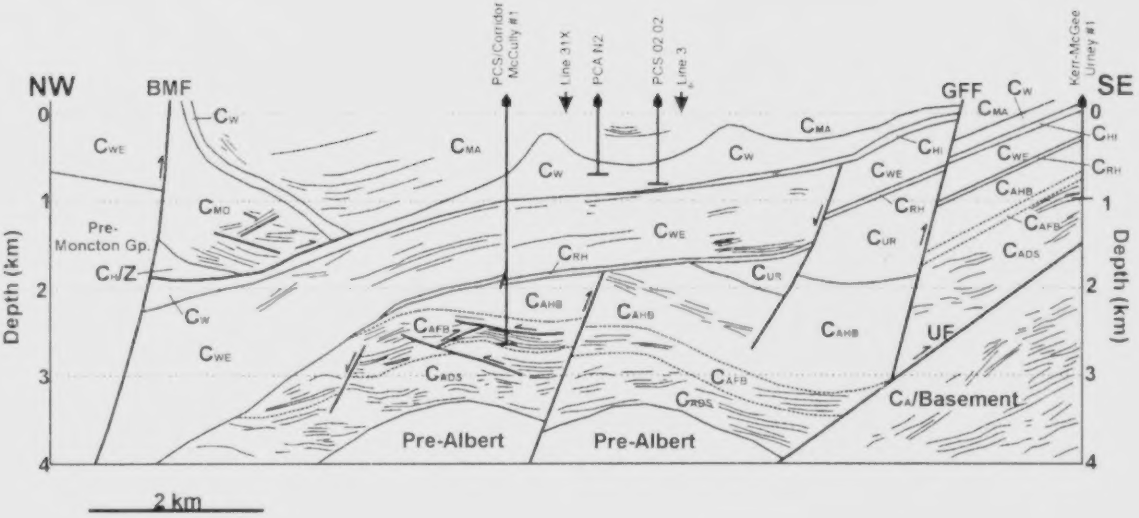


Figure 5. Interpretation of seismic line 2.

(Figure 9d). Drag of bedding into this fault suggests that the fault is of reverse displacement. Further to the southwest (at outcrop 7) Albert Formation micro- conglomerates, sandstones, mudstones and shales are steeply dipping to slightly overturned, and strike approximately northeast, parallel to the reverse-sense, northwest-side-up Kennebecasis River Fault which bounds the Albert Formation just to the northwest of Highway 1.

A stereonet of all fault orientations measured along Highway 1 (Figure 7f) shows two orientation sets: an east-trending set of normal (Figure 8a) and generally sinistral strike-slip faults, and a north- to northwest-trending set of normal faults. Northeast-trending faults are comparatively rare, even though northeast trending faults form the major structural control in the study area. Many of the normal faults in outcrop die out upward and are probably syndepositional structures.

Fault zones in the Highway 1 sections (Figure 9) were studied to assess the possibility that elevated porosity or permeability levels might be encountered adjacent to fault zones. In many faults that juxtapose sandstone against sandstone, there is a central fault core of clay gouge between 1 and 2 cm wide, surrounded by a damage zone of fractured rock and/or breccia which is in general between 3 and 5 cm wide. In many faults that cut shale, a gouge core exists but no damage zone is observed. In other cases, especially where displacements were demonstrably small, faults are marked by discrete fractures, and no gouge core or damage zone was developed.

Thin sections SFA–4 and SFA–3A (Figure 10) are taken from a normal fault zone pictured in Figure 9b; SFA–4 from the central part of the fault zone and SFA–3A from the damage zone. The rocks affected by the fault are dolomitic and organic shales. The fault zone is 30 cm across (Figure 9b) and is characterized by the presence of slickensided mineralized surfaces and microfaults which offset layering within the shales. The fault is well indurated and no gouge is present. In sample SFA–4 (Figure 10a), a fault core of intense deformation approximately 7 mm across can be

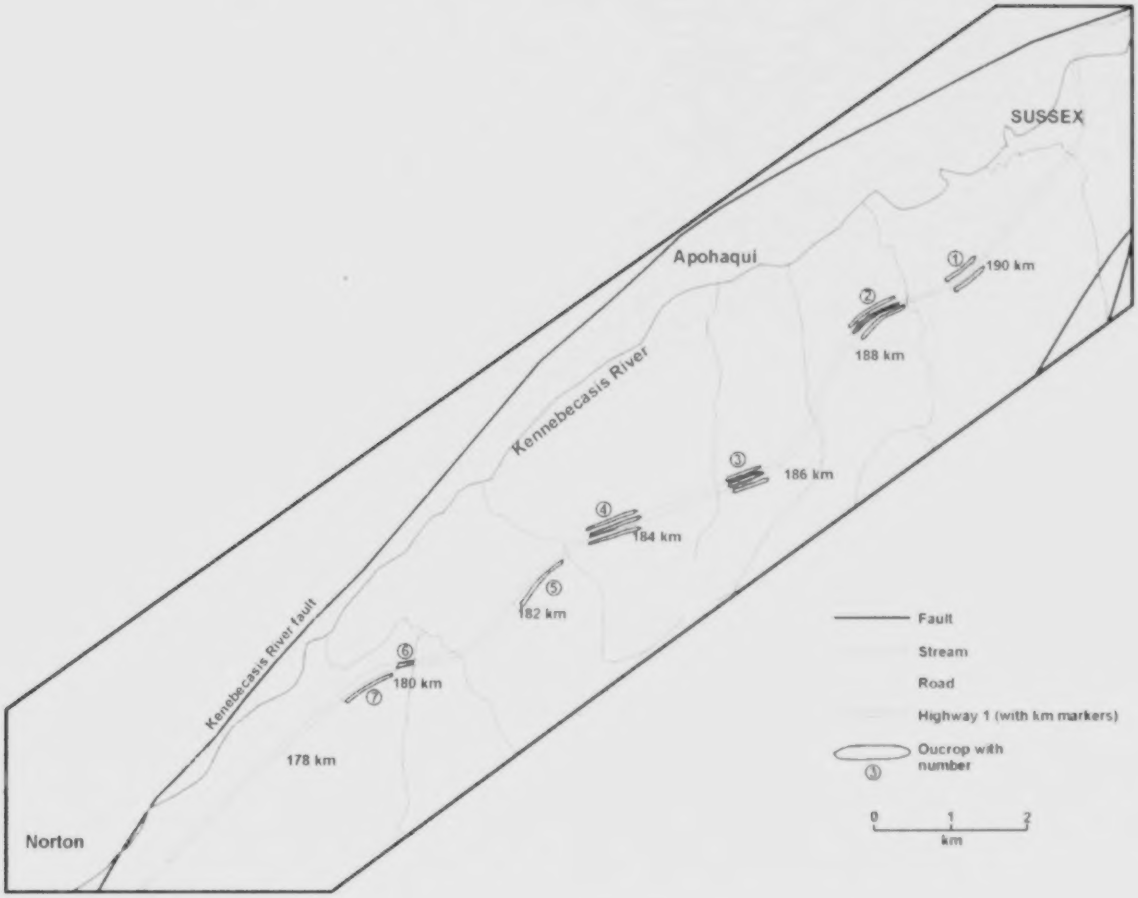

SUSSEX
Apohaqui
①
190 km
②
188 km
Kennebecasis River
③
186 km
④
184 km
⑤
182 km
⑥
180 km
⑦
178 km
Kenebecasis River fault
Norton
Fault
Stream
Road
Highway 1 (with km markers)
Oucrop with number
③
0
1
2
km

Figure 6. Map showing the locations of outcrops referred to in section 4.1.

delineated. Within the central zone, primary layering is not distinguishable. The central zone contains sub-mm scale riedel shears containing comminuted material and en-echelon veins, the orientation of which indicates normal movement. In the damage zone outside the central zone (Figure 10), primary layering is visible and is offset by ubiquitous carbonate veins, rare fractures containing cataclastic material, and microfaults with no apparent loss of cohesion. Further away from the central zone but still within the damage zone, most of the cross-cutting features are veins or styolites.

The Highway 1 section contains rocks affected by synsedimentary deformation processes (Figure 11). At outcrop 3, master bedding dips approximately 20° to the east, but is disrupted by intraformational folds and melange units. These features are thought to be related to synsedimentary slumps, because of the presence of undeformed master bedding, the presence of scours at the base of the units, and the presence of erosional or depositional contacts at the top of the units (Figure 11a). The units contain tight to isoclinal folds and refolded folds (Figures 11b, 11c) and minor thrust faults. They are in general remarkably coherent, with individual sedimentary layers traceable for metres or tens of metres laterally, in many cases through complex fold trains.

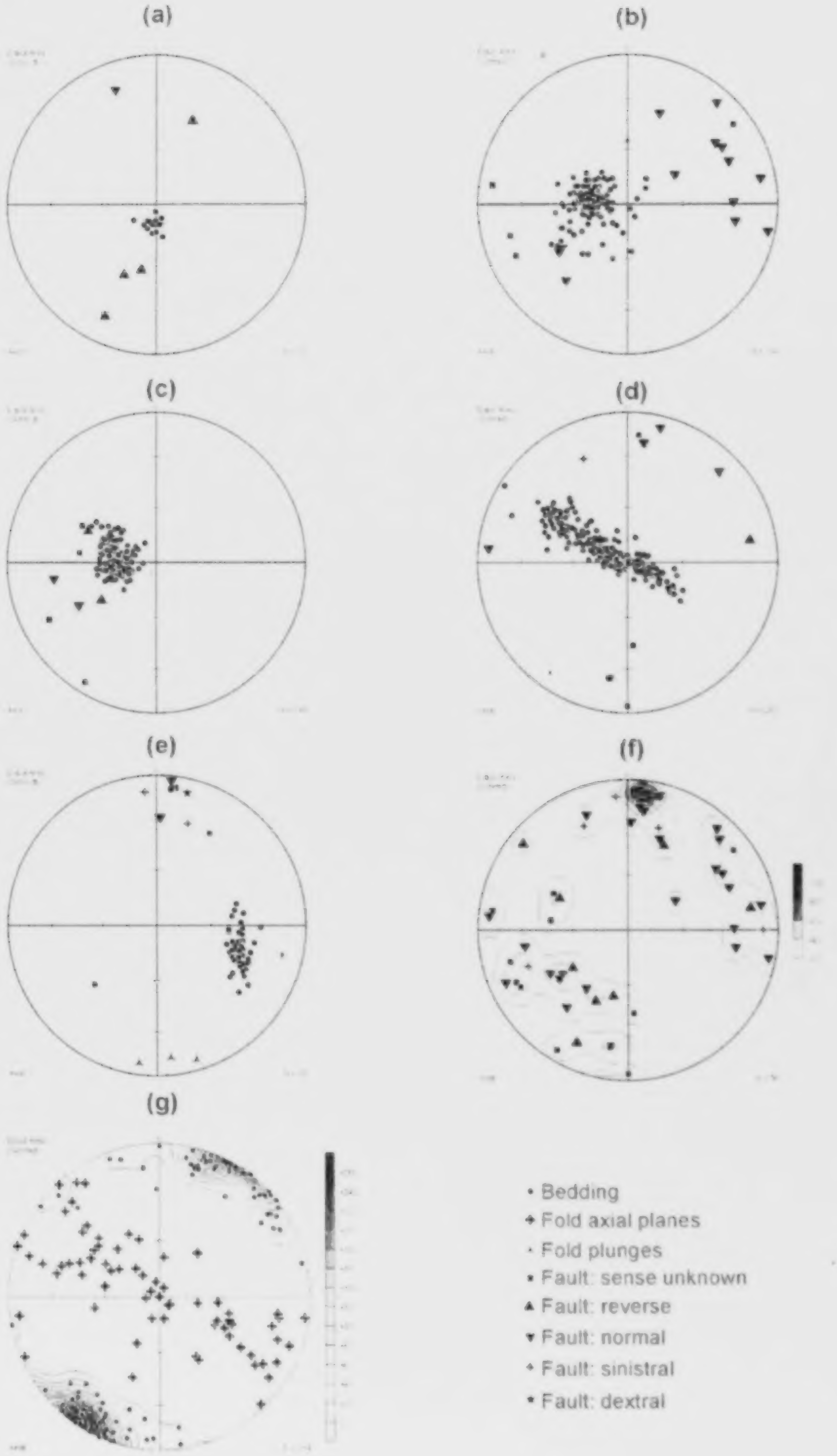


Figure 7. Stereonets showing orientation data from the Highway 1 section.

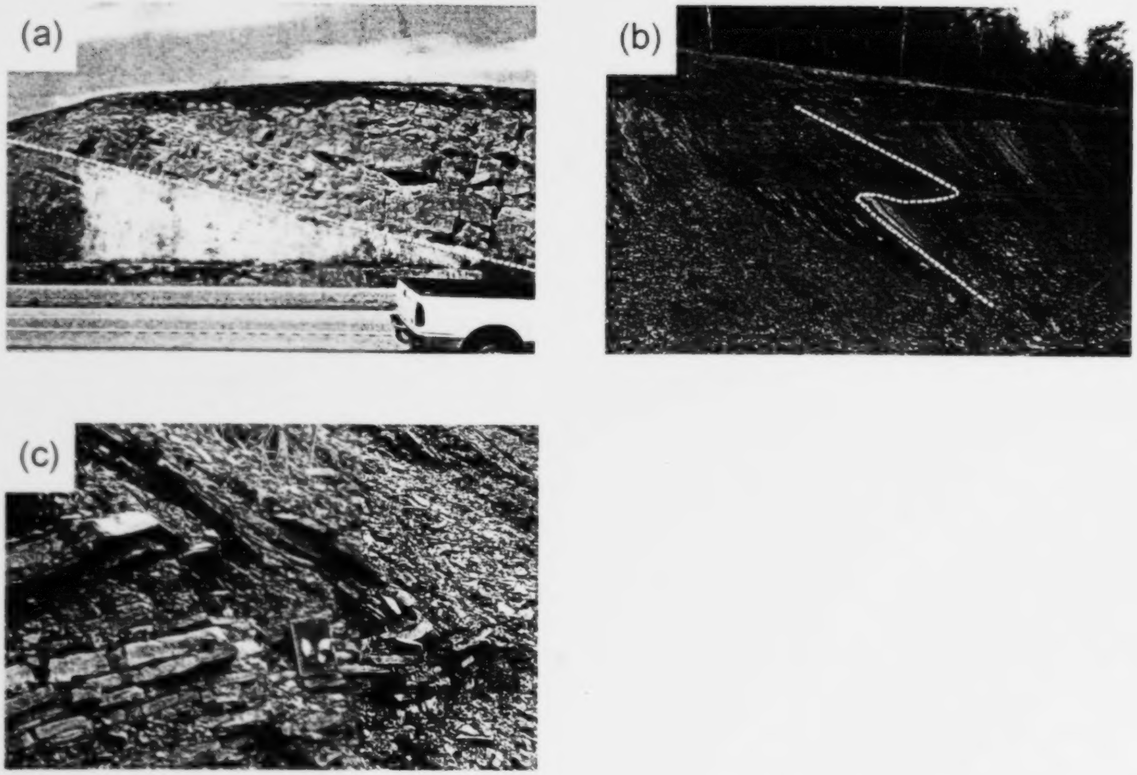


Figure 8. Geology of Highway 1.

Measurements of fold hinges and axial planes, corrected to restore master bedding to horizontal, are plotted on a stereonet in Figure 7g. Axial plane orientations plot on a great circle, while fold hinges form a point maximum. This pattern of fold orientations suggests that the direction of slumping was toward the southeast or the northwest (e.g., Bradley and Hanson 1998). Boudins are observed in the slump units at outcrop 3 and outcrop 5 (Figures 11d, 11e, 11f). Boudins are only found within slump units, suggesting their formation was related to the slumping process. The long axes of the boudins are parallel to fold hinges within the slumps. Boudins exhibit complex internal fold geometries (Figure 11f), including refolded folds and sheath folds. The author is not aware of any similar structures described in the literature and their detailed mechanisms of formation are not completely understood.

The triggering mechanism for the slump units cannot be established with confidence, but the fact that the Moncton Subbasin was subsiding rapidly during Albert Formation deposition (Martel 1987; Nickerson 1994) suggests they may have been triggered by syn-Albert seismic activity.

STRUCTURAL GEOLOGY OF THE WINDSOR GROUP

A structure contour map of the top of the Windsor Group has been prepared from seismic and borehole data (Figure 12). The map shows that the Penobsquis salt structure is an elongate,

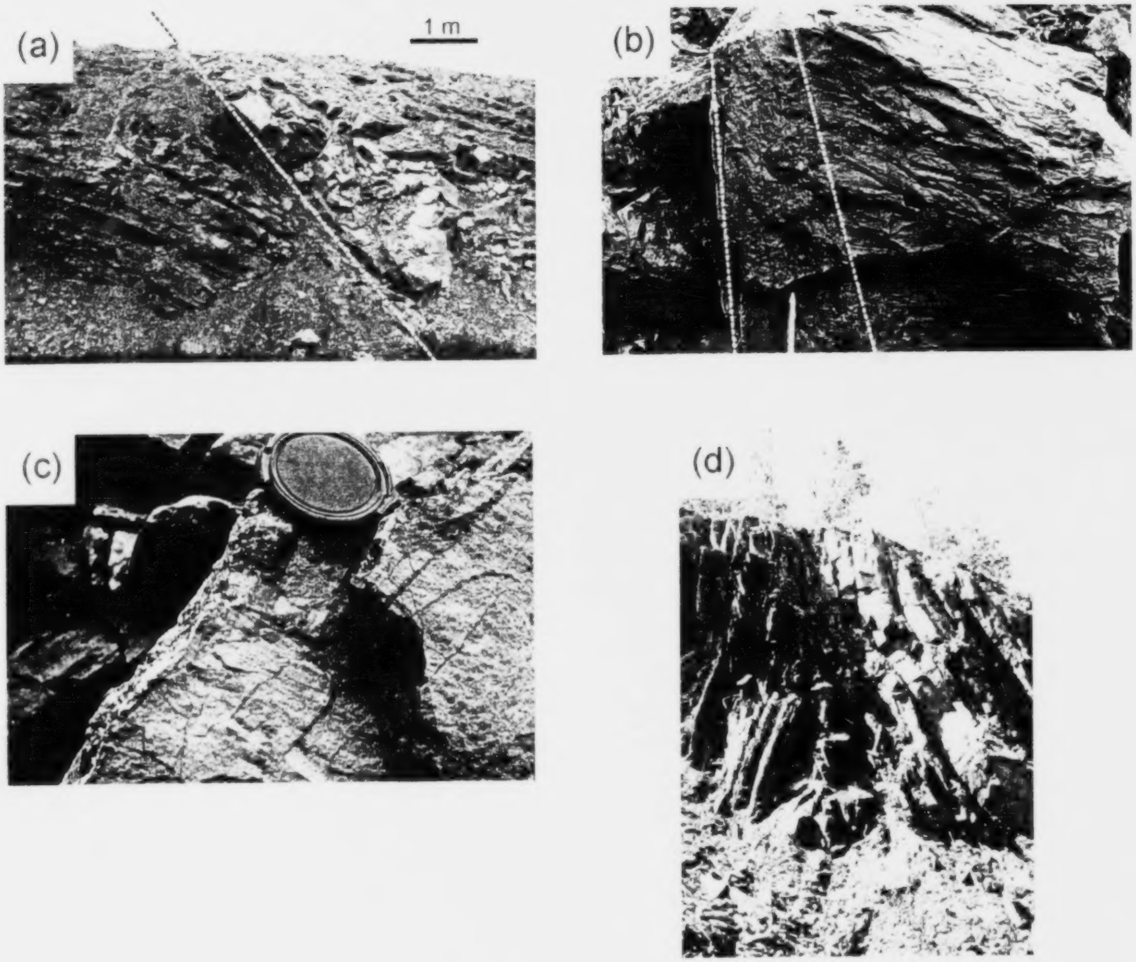


Figure 9. Faults in the Albert Formation.

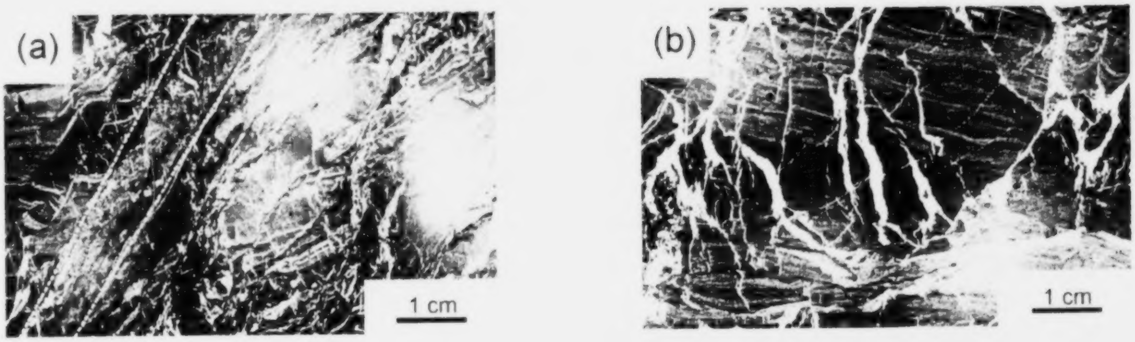


Figure 10. Thin sections of faults in the Albert Formation.

asymmetric linear structure with an irregular crest. Serial cross sections (Figure 13) show that the structure can be divided into two segments in terms of its structural style and trend. The southwestern segment (Figures 13a, 13b and 13c) trends approximately 055° and forms a relatively gentle asymmetric anticline verging toward the southeast. The northeastern segment (Figure 13d and 13e) trends approximately 070°, forms a highly asymmetric to overturned southeast-vergent anticline and is associated with a major 070°-trending reverse fault in the beds above the salt (see also Figure 3; Figure 14). It is unclear whether the salt has penetrated Mabou Group rocks; however, the association of the salt structure with normal and reverse faults in the cover suggests active diapirism with at least limited penetration (Davison et al. 1993).

It is clear from seismic interpretations and cross-section constructions that the Macumber and Upperton formations have not been significantly deformed, while the overlying Cassidy Lake and Clover Hill formations have flowed forming the salt ridge. This shows that there is a detachment horizon between the Upperton and Cassidy Lake formations. At Sussex Corner, Macumber limestone overlies red-grey polymictic conglomerates of the Hillsborough Formation. The upper Macumber limestone is folded in this area (Figure 15). The folds generally plunge moderately to shallowly to the northeast and have near-vertical axial planes, whereas the basal Macumber Formation and underlying Hillsborough Formation are not folded. The folds have previously been interpreted as intraformational slump structures (McCutcheon 1981). However, the similarity in orientation and style of the folds and the lack of any evidence for scours at the base of folded units, suggests that the folds are tectonic in origin. Additionally, the style of the folding, that is, upright to inclined folds overlying a basal décollement, is similar to the large-scale folding of Windsor Group salt (Figure 13). The folds are therefore interpreted to be related to detachment tectonics during salt movement, suggesting that the décollement structure is not a simple feature confined to one stratigraphic level.

There is evidence for structural dislocation along the ore zone. Sylvinite in the ore zone is highly lineated in some boreholes, with sylvite crystals having aspect ratios of 4:1 and greater. In other boreholes the ore possesses a compositional layering, with cm-scale interbanding of fine-grained sylvite and blue halite, and clean translucent or light grey halite. In borehole PCS 02 04 (Figure 13b; Plate 1 for location; Appendix 1 for log), the Upper Halite member and Ore Zone are structurally repeated across a strongly lineated ore section; this deformed ore section is interpreted to represent a northwest-dipping, low-angle ductile shear zone with reverse displacement.

Borehole evidence shows that structural repetition of the evaporite stratigraphy is common (e.g., Figure 13a). In many cases the repeated stratigraphy is associated with a shallowly to moderately dipping schistosity which is parallel or subparallel to primary layering. These observations are consistent with the presence of recumbent to moderately inclined isoclinal folds. In borehole M–4A (Plate 1; Figure 13c; Appendix 1), the entire evaporite stratigraphy is overturned by a large-scale northwest-verging fold. In borehole C–2 (Plate 1) anhydrite lies above Mabou Group siltstones across a faulted contact. It is suggested that the anhydrite belongs to the Clover Hill Formation, and the borehole cut an overturned fold in the evaporites associated with a reverse fault in the Mabou Group. In some cases the limbs of the folds are highly attenuated; for example, in borehole D–3 (Plate 1; Appendix 1) the middle halite member near the base of the hole is about 55 cm thick. In

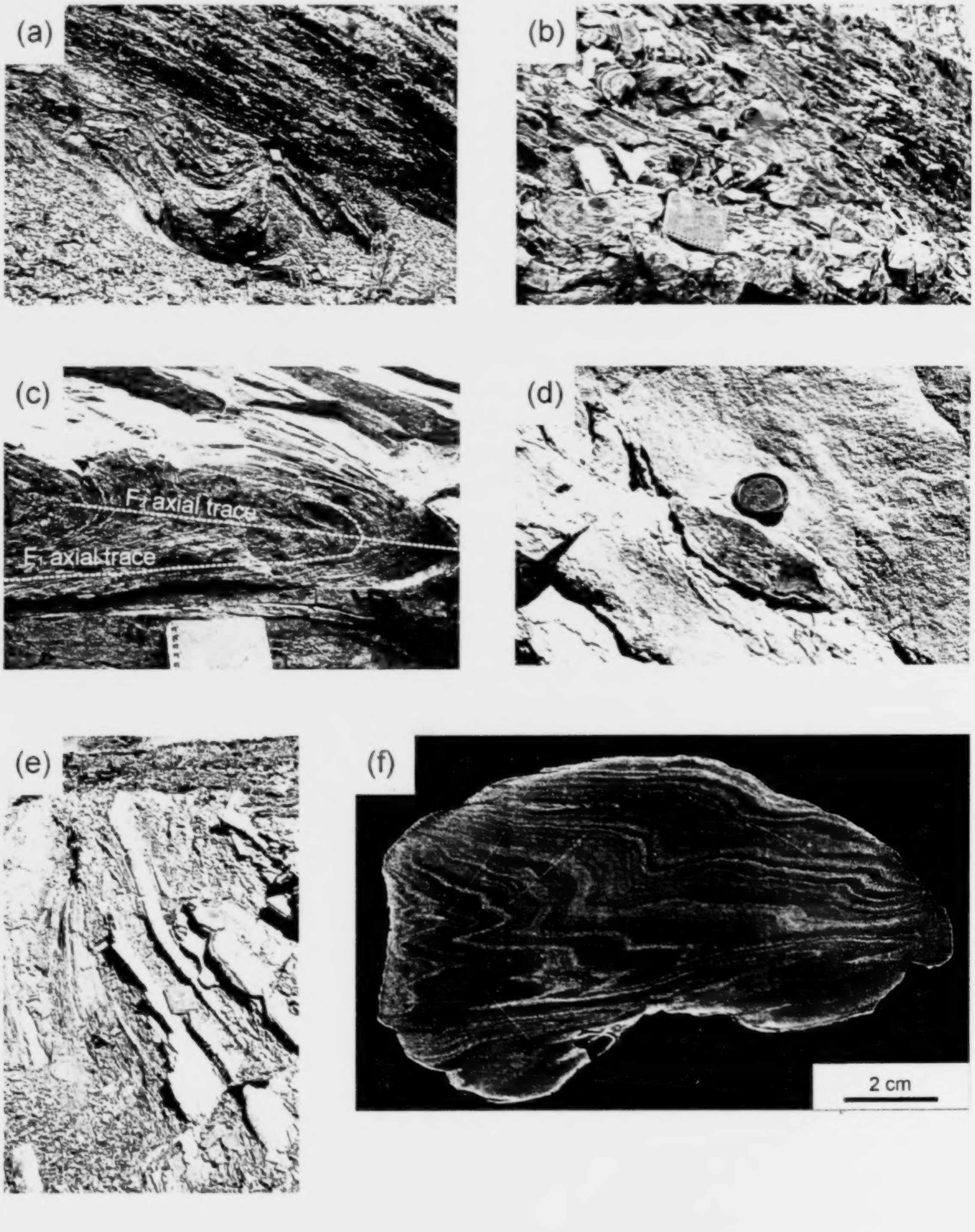

(a)
(b)
(c)
F_2 axial trace
F_1 axial trace
(d)
(e)
(f)
2 cm

Figure 11. Syn-sedimentary structures observed along Highway 1.

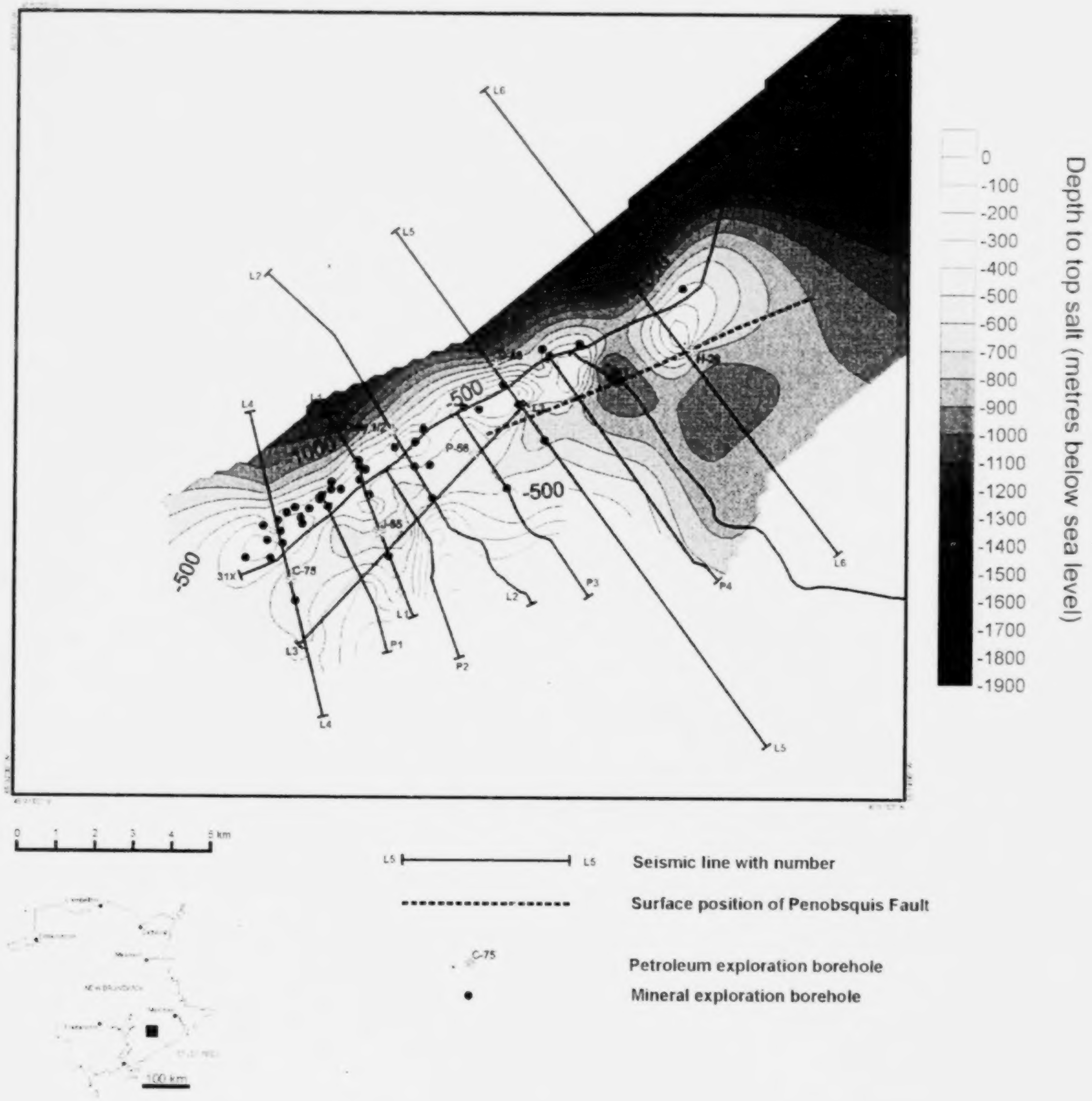

L6
L5
L2
L4
L3
L1
P1
P2
P3
P4
31X
C-75
P-66
J-65
-500
-500
-500
-1000
Depth to top salt (metres below sea level)
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
-1500
-1600
-1700
-1800
-1900
0 1 2 3 4 5 km
Seismic line with number
Surface position of Penobsquis Fault
Petroleum exploration borehole
Mineral exploration borehole
100 km

Figure 12. Structure contour map of the depth to top salt in metres below mean sea level.

borehole H–5 (Plate 1; Appendix 1) the same unit is more than 30 m thick. The presence of steep fabrics and the presence of folded schistosity within the evaporite section suggests that refolding has occurred; this is supported by observations of refolded isoclinal folds in the PCS mine workings, and cross-section interpretations based on borehole and seismic data (Figure 13a).

In some cores that reach or approach the base of the basal halite, shallowly dipping mylonite zones are present. Examples include boreholes B–3 , E–3, PCS 02 01, PCS 02 02, and PCS 02 04 (see Plate 1 for locations). In the lower 50 m or so of B–3 (Appendix 1), coarse- to very coarse grained, clean to slightly anhydritic halite gives way to coarse-grained, clean schistose halite (Figure 16a). The schistosity becomes more pervasive downward, for example schistose halite grades downward

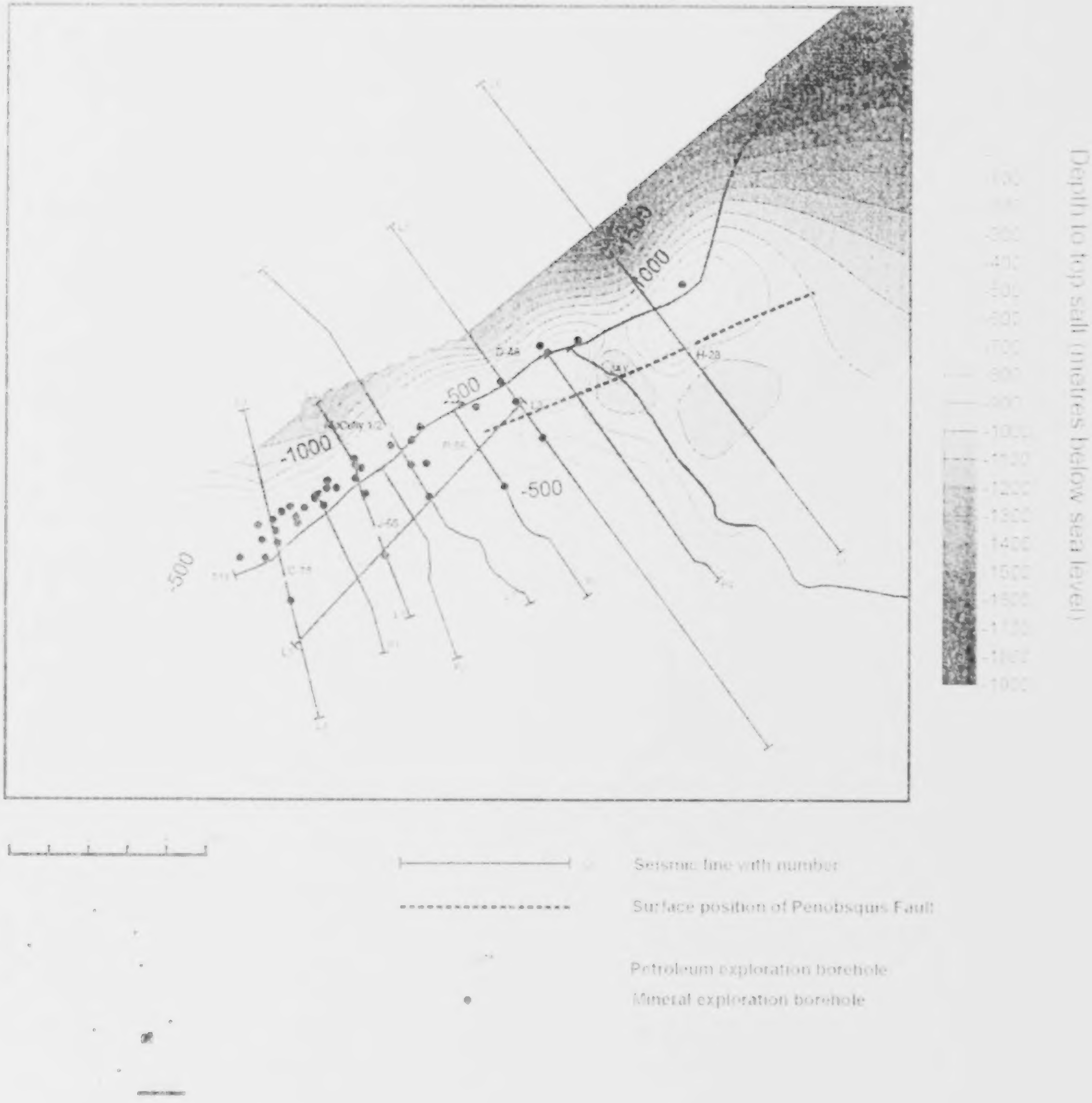

Depth to top salt (metres below sea level)
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
-1500
-1600
-1700
-1800
-1900
-1000
-1500
-500
-500
-500
-1000
-500
D-44
H-28
P-84
Seismic line with number
Surface position of Penobsquis Fault
Petroleum exploration borehole
Mineral exploration borehole

Figure 12. Structure contour map of the depth to top salt in metres below mean sea level.

borehole H-5 (Plate 1: Appendix 1) the same unit is more than 30 m thick. The presence of steep fabrics and the presence of folded schistosity within the evaporite section suggests that refolding has occurred; this is supported by observations of refolded isoclinal folds in the PCS mine workings, and cross-section interpretations based on borehole and seismic data (Figure 13a).

In some cores that reach or approach the base of the basal halite, shallowly dipping mylonite zones are present. Examples include boreholes B-3 , E-3, PCS 02 01, PCS 02 02, and PCS 02 04 (see Plate 1 for locations). In the lower 50 m or so of B-3 (Appendix 1), coarse- to very coarse grained, clean to slightly anhydritic halite gives way to coarse-grained, clean schistose halite (Figure 16a). The schistosity becomes more pervasive downward, for example schistose halite grades downward

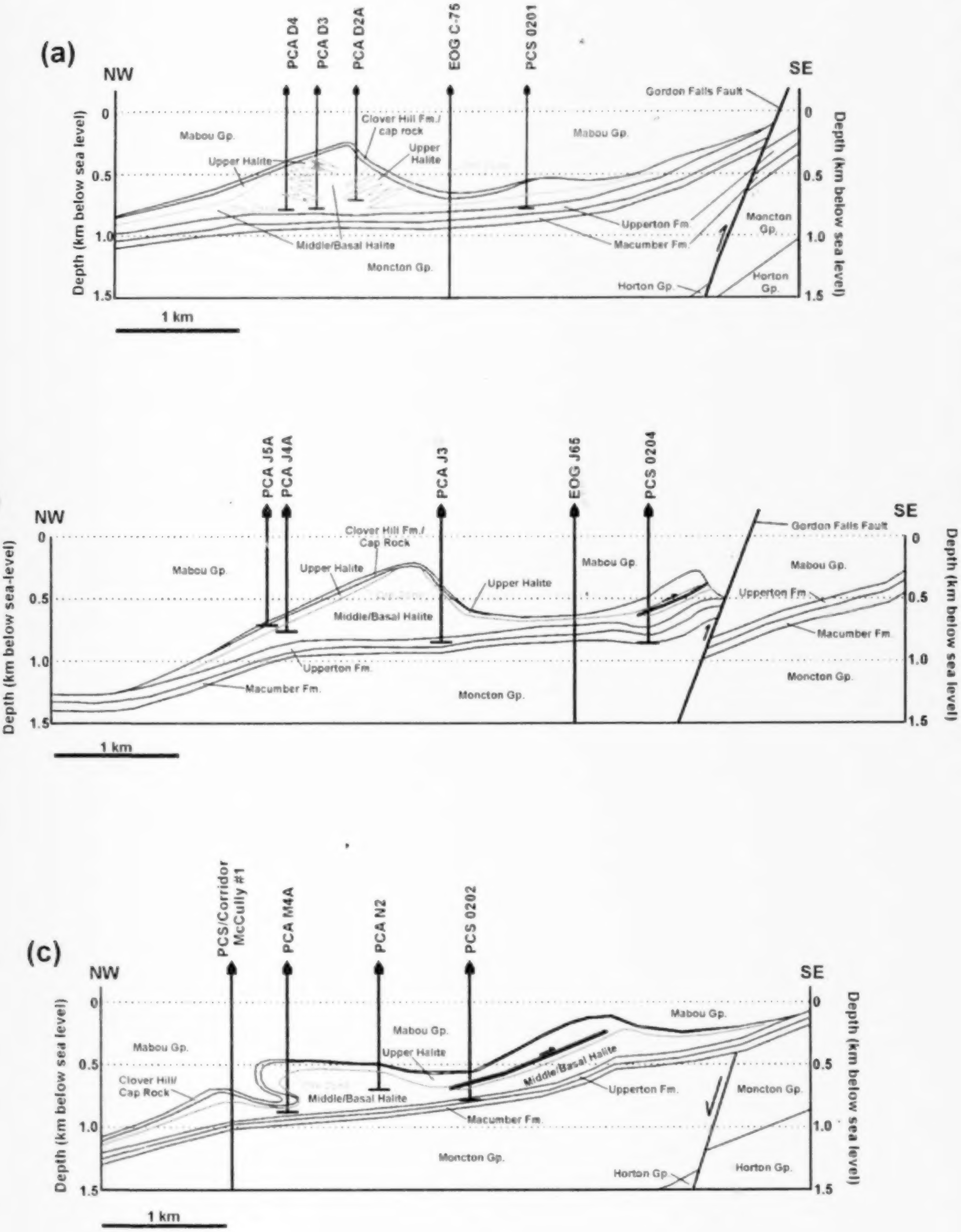

(a)
NW
SE
PCA D4
PCA D3
PCA D2A
EOG C-75
PCS 0201
Gordon Falls Fault
Clover Hill Fm./
cap rock
Upper
Halite
Mabou Gp.
Upper Halite
Middle/Basal Halite
Moncton Gp.
Upperton Fm.
Macumber Fm.
Moncton
Gp.
Horton Gp.
Horton
Gp.
Depth (km below sea level)
0
0.5
1.0
1.5
1 km
(b)
NW
SE
PCA J5A
PCA J4A
PCA J3
EOG J65
PCS 0204
Gordon Falls Fault
Clover Hill Fm./
Cap Rock
Mabou Gp.
Upper Halite
Middle/Basal Halite
Upperton Fm.
Macumber Fm.
Moncton Gp.
Depth (km below sea-level)
Depth (km below sea level)
0
0.5
1.0
1.5
1 km
(c)
NW
SE
PCS/Corridor
McCully #1
PCA M4A
PCA N2
PCS 0202
Mabou Gp.
Clover Hill/
Cap Rock
Upper Halite
Middle/Basal Halite
Upperton Fm.
Macumber Fm.
Moncton Gp.
Horton Gp.
Depth (km below sea level)
0
0.5
1.0
1.5
1 km

Figure 13. Cross sections a to f of the Penobsquis salt structure.

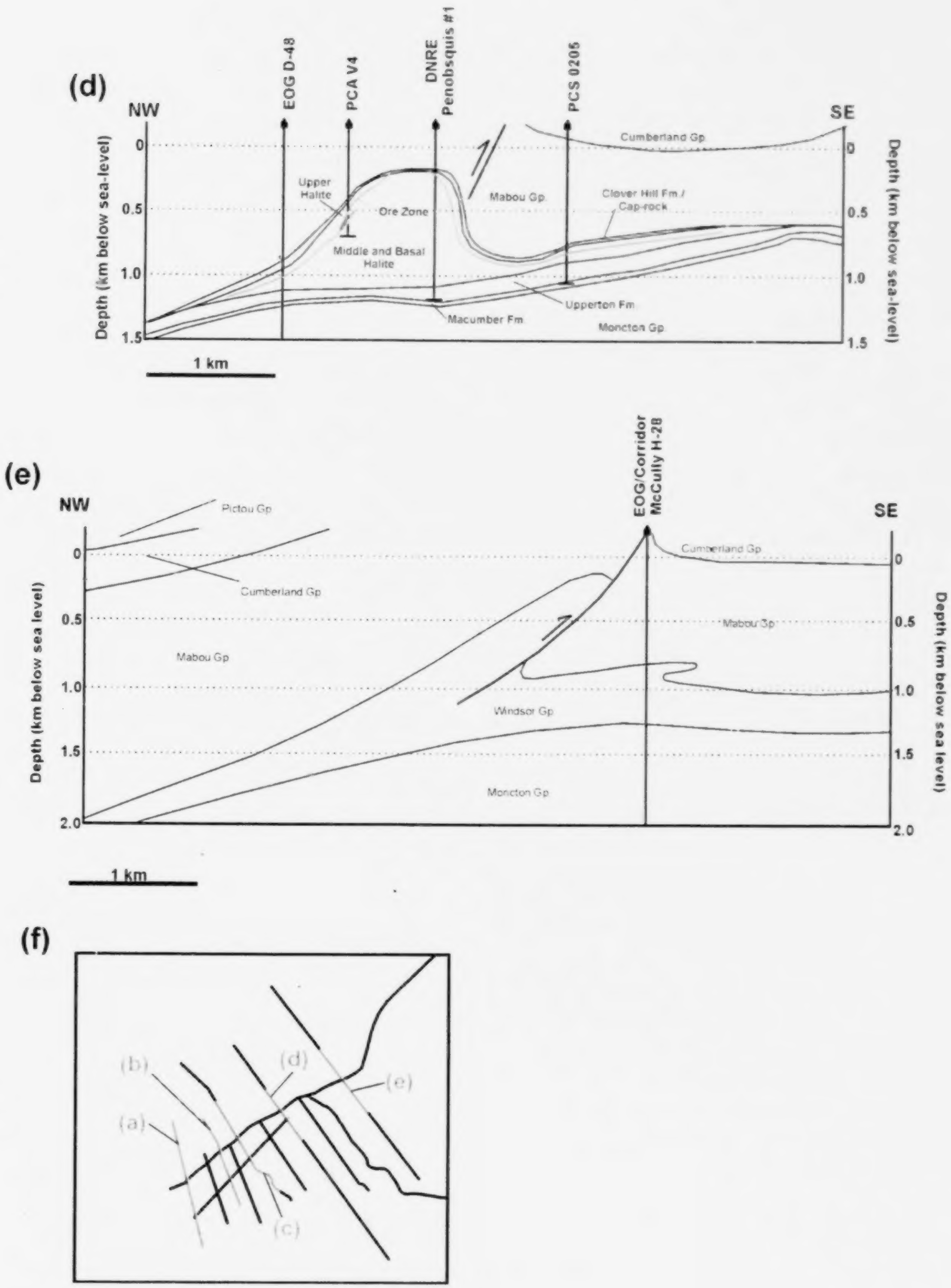

(d)
NW
SE
EOG D-48
PCA V4
DNRE Penobsquis #1
PCS 0205
Depth (km below sea-level)
0
0.5
1.0
1.5
Cumberland Gp
Upper Halite
Ore Zone
Mabou Gp
Clover Hill Fm / Cap-rock
Middle and Basal Halite
Upperton Fm
Macumber Fm
Moncton Gp
1 km
(e)
NW
SE
EOG/Corridor McCully H-28
Pictou Gp
Cumberland Gp
Mabou Gp
Windsor Gp
Moncton Gp
Depth (km below sea level)
0
0.5
1.0
1.5
2.0
1 km
(f)
(a)
(b)
(c)
(d)
(e)

Figure 13. (Continued)

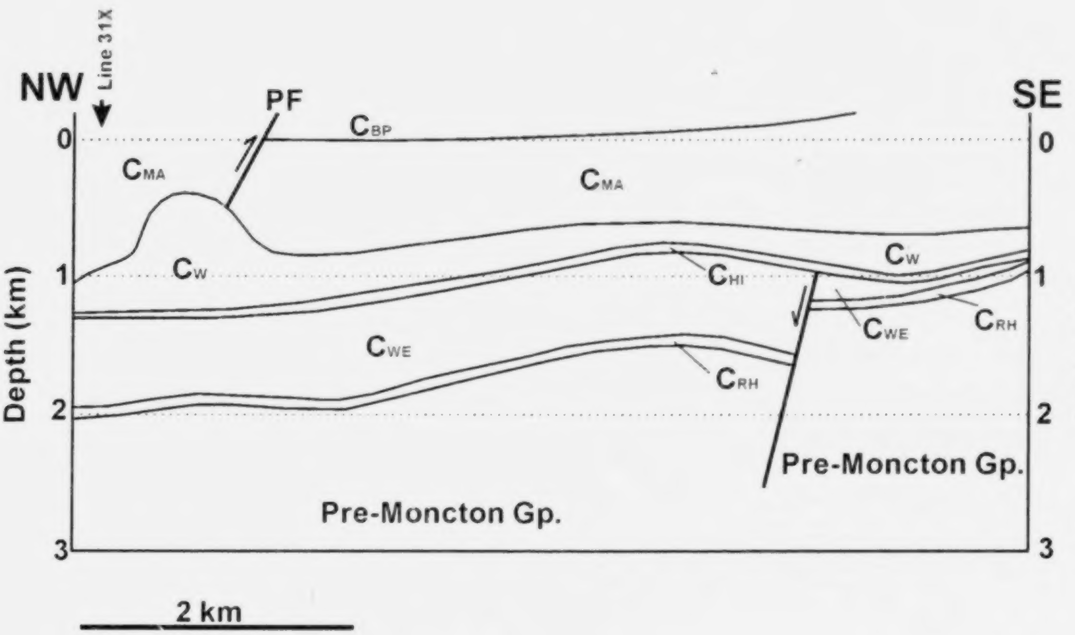


Figure 14. Interpretation of seismic line PIC-4.

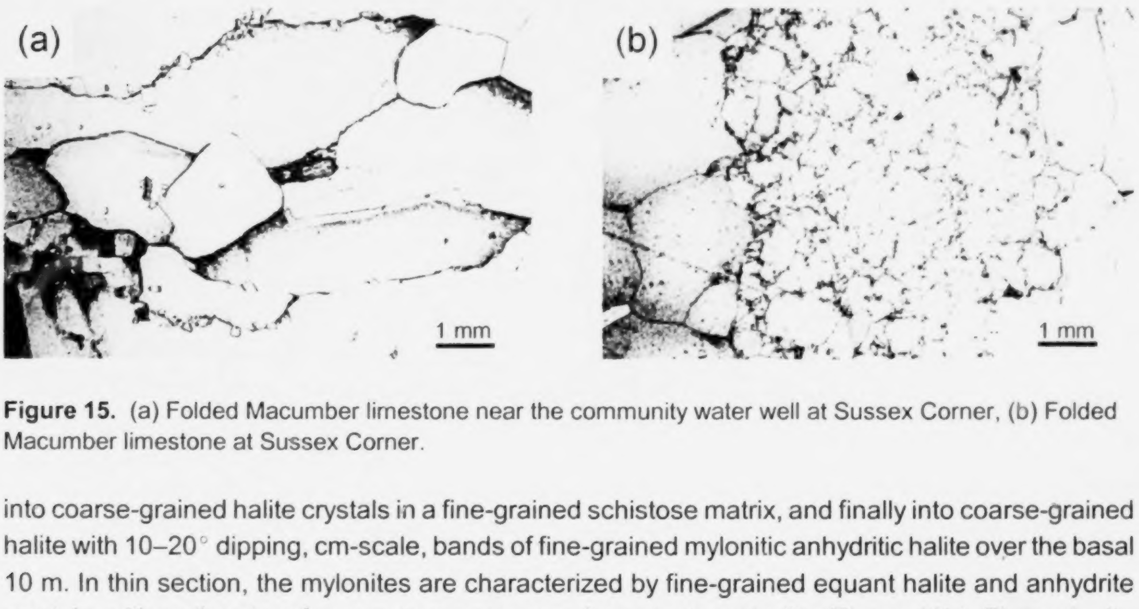


Figure 15. (a) Folded Macumber limestone near the community water well at Sussex Corner, (b) Folded Macumber limestone at Sussex Corner.

into coarse-grained halite crystals in a fine-grained schistose matrix, and finally into coarse-grained halite with 10–20° dipping, cm-scale, bands of fine-grained mylonitic anhydritic halite over the basal 10 m. In thin section, the mylonites are characterized by fine-grained equant halite and anhydrite crystals, with wall-rocks of coarse to very coarse, foam-textured halite (Figure 16b). The mylonite bands are observed to be asymmetrically folded. The schistosity becomes shallower downward over a 50 m interval, from about 45–50° near the top to 10–20° near the base. The core containing the contact with the underlying Upperton Formation anhydrite is missing; however, according to previous logs (Dickie 1977), the contact is sharp and dips 18–20°. Cores from other boreholes show similar relationships, although generally with a lesser thickness of mylonitic halite. It appears that there is a significant low-angle, bedding-parallel shear zone lying near the base of the Cassidy Lake Formation. It is suggested that this shear zone is related to the detachment between the Upperton and Cassidy Lake formations. It therefore does not have a consistent sense of movement, but and Cassidy Lake formations. It therefore does not have a consistent sense of movement, but represents a rheological boundary across which salt has flowed during the formation of the Penobsquis salt structure. It should be noted that the shear zone is not observed in all holes that intersect the base of the Cassidy Lake Formation, notably PCS 02 03 (Plate 1 for location). This is taken as evidence that PCS 02 03 was drilled outside of the area in which salt flow took place.

Normal and reverse faults occur in the strata overlying the salt structure. In core samples from the cap rock (Figure 17) steep brittle-ductile shears are observed. These samples contain shear-band fabrics that reflect high strains (Passchier 1984). Shear band fabrics indicate both reverse and normal senses of movement. On seismic lines 6 and PIC–4 (Figures 3 and 14), a reverse fault is interpreted to cut the Boss Point Formation above the salt ridge. The fault appears to link with the overturned fold imaged on line 6 (Figure 3). Field evidence for this fault is seen near the H–28 well site (Plate 1 for location). Boss Point Formation rocks are steeply dipping to slightly overturned and facing southeast (Figure 18), indicating the presence of a reverse-displacement fault to the north of H–28. The elongate salt body is associated with a major northeast-trending fault system in the strata overlying the salt (see also Gussow 1953; Nickerson 1994).

Reflectors in the Mabou Group show some thinning onto the salt structure (e.g., Figure 3), demonstrating that some salt flow must have occurred during Mabou deposition, forming a relatively low-amplitude salt pillow. Both the Cumberland and Mabou groups are folded into an elongate, linear anticline above the salt structure (Plate 1), and salt-linked faults cut the Cumberland Group. Therefore the initial salt pillow was modified into a high-amplitude salt wall during a phase of salt deformation that occurred after Cumberland Group deposition.

FAULT KINEMATICS AND TIMING

Field evidence and interpretation of seismic reflection profiles have been used to evaluate the kinematic history of individual faults in the study area and thereby establish a tectonic history.

Evidence for early subsidence of the Moncton Subbasin is shown by the Gordon Falls Fault. Interpretation of seismic line 2 (Figure 5), based on borehole control from PCS/Corridor McCully 1, and the thickness of the Hiram Brook Member in the McCully area, shows that this roughly east-west trending fault has approximately 1200 m of Weldon Formation rocks in its hanging wall to the north. There is no Weldon Formation present in surface exposures to the south of the fault, or in the Kerr-McGee Urney 1 borehole in the footwall (Figure 5; Plate 1 for location). This geometry requires downthrow of the north side of the Gordon Falls Fault (i.e., fault movement in a normal sense) prior to the deposition of Moncton Group rocks.

Albert Formation rocks contain a number of thrust faults and higher angle reverse structures which do not penetrate the major pre-Moncton unconformity (e.g., Figure 5, in the Albert Formation near the base of PCS/Corridor McCully 1). In general, reflectors in Horton Group rocks are imaged as undulating and discontinuous features (Figures 3, 4, and 5), while reflectors in younger rocks are more continuous and undisturbed in appearance. In the field, Albert Formation rocks are more deformed than younger rocks, as is also the case in the Hillsborough area (St. Peter and Johnson

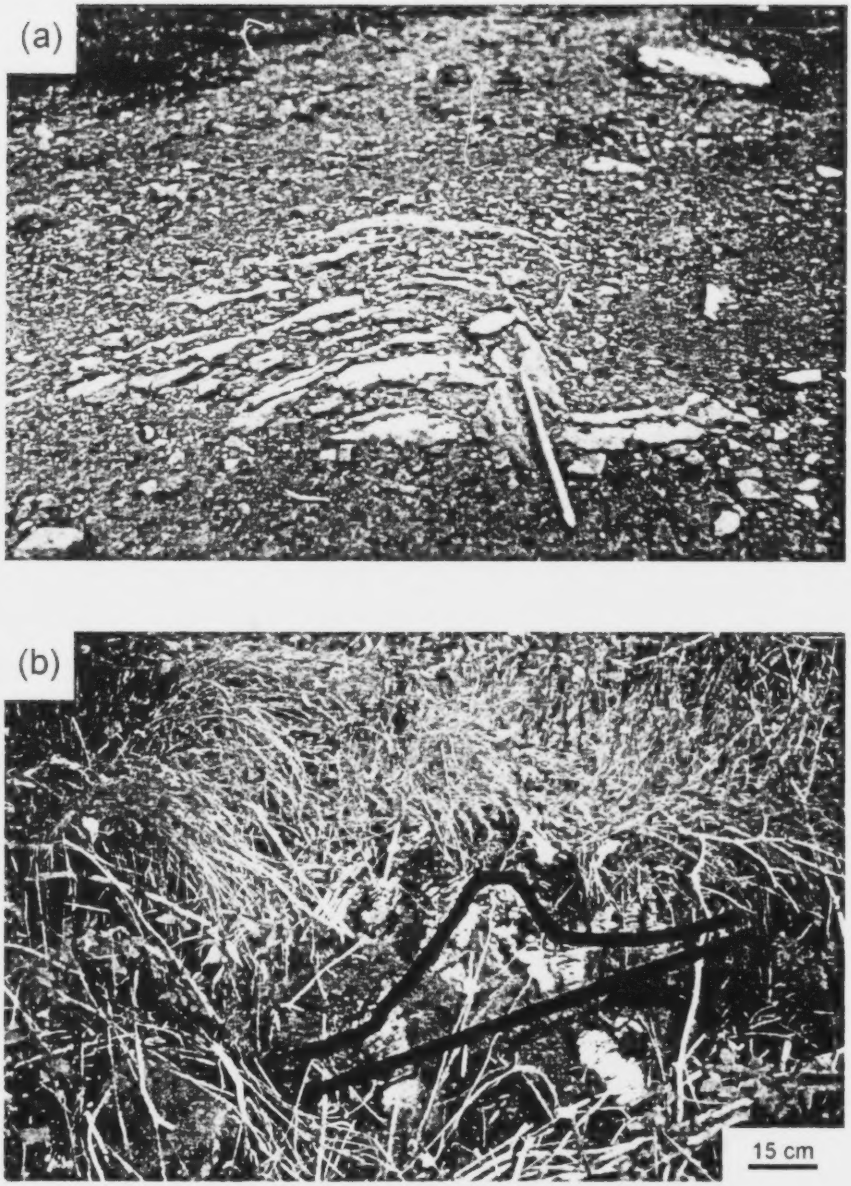


Figure 16. Photomicrographs of salt thin sections taken from borehole B-3.

1997; Wilson 2002). This deformation reflects a period of basin inversion that resulted in uplift and formation of the pre-Moncton unconformity.

A northwest-dipping fault cutting the Horton and Moncton groups and with apparent normal displacement is clearly imaged in the southeastern parts of lines 6, 5, and 2 (Figures 3, 4, and 5). The Weldon Formation section is dramatically thinner to the southeast of the fault. The fault does not cut overlying Windsor Group rocks, and is interpreted to be a Late Tournaisian to Early Viséan normal fault. Weldon Formation reflectors onlap onto the Round Hill Formation on the hanging wall side of the fault (Figures 3 and 5), suggesting that the structure was active as a growth fault during

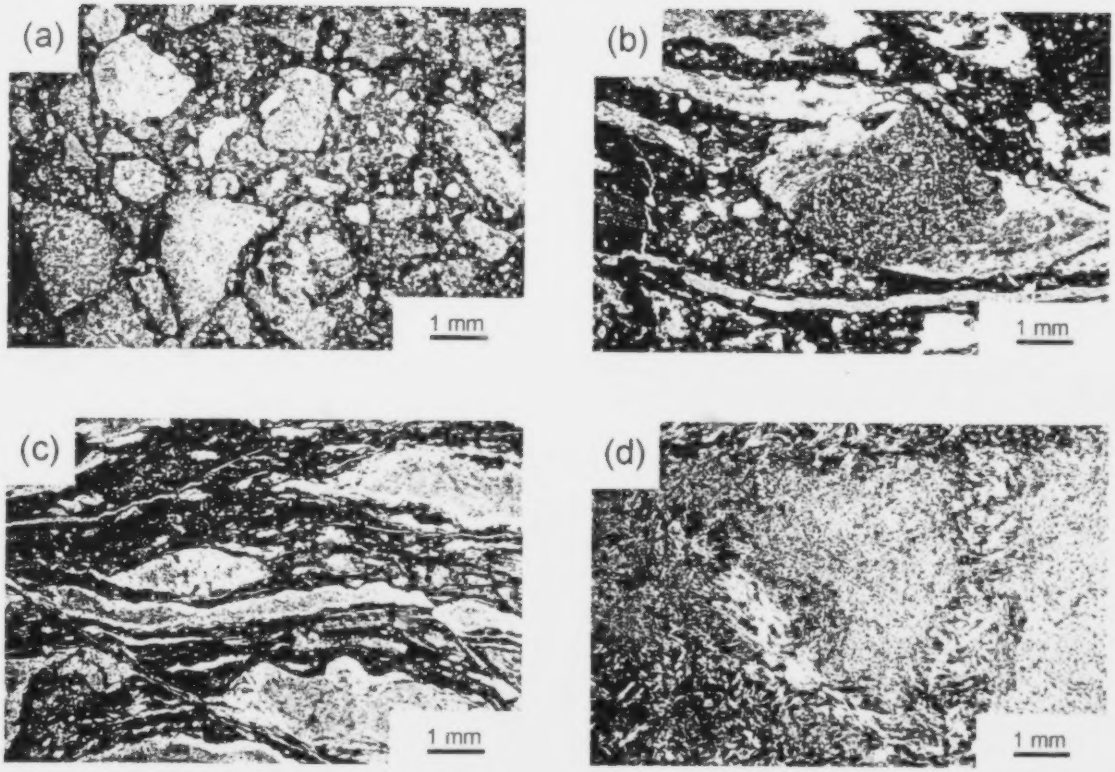


Figure 17. Photomicrographs of cap rock samples taken from mineral exploration core.

Weldon deposition. Another possibility is that the fault is a strike-slip fault. Jenyon (1986) noted that 'a salt interval may under certain circumstances [e.g., strike-slip faulting] act as a form of insulating layer, preventing some types of faulting below it from affecting the [salt] overburden'. In other words, differential movement between rocks below and above salt is accommodated by flow of the salt. Strike-slip movement occurs below the salt, but does not propagate above it. An example is described in Jenyon (1986; his figure 2.15). A strike-slip interpretation seems less likely because the Weldon Formation is not particularly variable in thickness parallel to the fault; hence, strike-slip movements on the fault could not produce the observed thickness difference in the Weldon Formation across the fault.

At the northwest end of lines 6, 5 and 2 (Figures 3, 4 and 5), the seismic interpretations show a wedge-shaped body of rock that is both underlain and overlain by rocks of the Macumber and Upperton formations, and bounded to the northwest by the Berry Mills Fault (Figure 5). Three hypotheses are advanced to explain the origin of the wedge:

1. The wedge consists of evaporites of the Cassidy Lake and/or Clover Hill formations. This hypothesis is rejected, for two reasons. Firstly, gravity modelling by Durling and Howells (2002) shows that there is no gravity anomaly associated with the wedge. Secondly, seismic interpretations show that the wedge reaches the surface to the northwest of Macumber Formation outcrops and southeast of the Berry Mills Fault in the Smiths Creek area (Plate 1; Figure 5). If the wedge

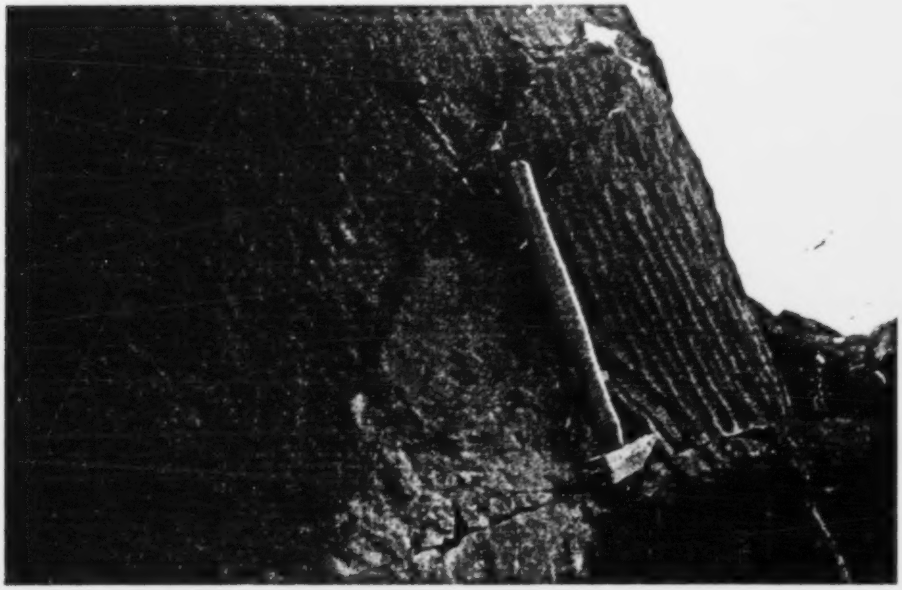


Figure 18. Outcrop of steeply dipping rippled sandstone of the Boss Point Formation near the H-28 wellsite.

consisted of salt, sinkholes and karst topography would be expected to occur in this area. The absence of any sinkholes to the northwest of the area of Macumber and Upperton outcrop argues against the wedge consisting of salt.

2. The wedge consists of Mabou Group rocks. The wedge is in thrust contact with overlying Mabou and Windsor Group rocks which have been thrust from the southeast (Wilson 2003). This hypothesis cannot explain the pattern of reflectors in the Mabou Group above the wedge (see hypothesis 3 below). Also, there is no field evidence that Windsor Group rocks overlie Mabou Group rocks in the Smiths Creek area. In the field, the rocks underlying the Macumber Formation generally consist of red-brown micaceous fine sandstone and siltstone, which resemble the Weldon Formation more than they resemble Mabou Group lithologies. Drill holes SC–24 and SC–27 (see Plate 1; Crosby and Waugh 1975) were drilled through the Macumber Formation into the underlying wedge. The rocks below the Macumber Formation in the wedge consist of red or grey polymictic conglomerate and red-brown micaceous siltstone and fine sandstone. Again, these lithologies are more like the Hillsborough and Weldon formations than the Mabou Group. There is no evidence of significant deformation in the Macumber limestone or in the rocks underlying the limestone, arguing against the presence of a major thrust fault at the contact between the Windsor Group and the underlying wedge.

3. The wedge consists of Moncton Group and older rocks that have been thrust to the southeast along the basal Windsor rocks (St. Peter, personal communication, 2003). This is the preferred interpretation. On seismic line 6 (Figure 3), a local intra-Mabou unconformity is imaged in the Mabou Group rocks that overlie the wedge. Relatively steep reflectors in the lower Mabou are overlain by shallower reflectors in the upper Mabou. This indicates that the wedge was likely thrust southeastward during the early stages of Mabou deposition, and ceased to move, or moved more

southeastward during the early stages of Mabou deposition, and ceased to move, or moved more slowly, during the late stages of Mabou deposition. The Cumberland Group cuts progressively deeper into the Mabou Group toward the northwest where it overlies the wedge (Figures 3, 4 and 5), suggesting that the Mabou Group over the wedge was uplifted prior to Cumberland Group deposition. It is possible that the Mabou/Windsor contact was reactivated as a thrust at this time. This would explain the presence of apparent duplex and backthrust structures in the wedge toe which are imaged on seismic line 2 (Figure 5). It is possible that the wedge contains Horton Group rocks, in which case the duplex and backthrust structures may provide traps for hydrocarbon accumulations. However, the pre-Moncton unconformity cuts down through the Horton Group toward the northwest, and it may be that Moncton Group rocks directly overlie basement in the wedge.

Field and seismic data demonstrate the presence of a system of late contractional structures. The latest movements recorded on the Berry Mills, Gordon Falls, Urney and Clover Hill faults are reverse displacements (Figures 3, 4 and 5). The Berry Mills and Clover Hill faults appear to have been long-lived structures which have accommodated Acadian as well as Carboniferous movement (e.g., Leger and Williams 1986), and they both show apparent reverse displacements of Mabou Group rocks. The magnitude of such movements is large, with up to 2 km of reverse displacement on the Berry Mills Fault. There is approximately 500 m displacement of Mabou Group rocks across the Gordon Falls Fault (Figures 4 and 5). The Gordon Falls Fault appears to link at depth with a lower angle thrust fault (e.g., Figure 5), referred to as the Urney Fault. The Urney anticline (Plate 1) is interpreted as a fault-related fold associated with the Urney Fault. Field mapping (Plate 1) shows the Urney Fault cropping out to the southwest of the Urney anticline, where the Round Hill Formation is thrust over younger rocks.

The Gordon Falls Fault has been offset by and northwest-trending faults, for example north of Picadilly (Plate 1), where seismic interpretations suggest that the Gordon Falls Fault is offset in a sinistral sense. The faults may be transfers contemporaneous with late thrusting, or may represent a set of later structures. A transfer origin is favoured, because there is no evidence of significant sinistral displacement of Windsor and Moncton bedding ridges in the Picadilly area (Plate 1).

The timing of the late contraction recorded in fault displacements has some constraints. The Berry Mills Fault cuts Pictou Group rocks (Westphalian C), the youngest rocks exposed in the area (Plate 1; St. Peter 2002). As argued above, the main phase of salt deformation in the study area is post-Westphalian A. The asymmetry of the Penobsquis salt structure, the presence of southeast-directed thrusts within the salt and association with reverse faults in the salt cover demonstrates that salt deformation is related to tectonic contraction. Salt movement is interpreted to be contemporaneous with late reverse movement on northeast-trending faults. The absence of rocks younger than Westphalian C in the study area means that no upper limit for the age of late contraction can be established. However, the contractional nature of the deformation, and its occurrence post-Westphalian C, supports an Alleghenian age for the deformation.

Evidence exists for limited strike-slip displacement along northeast-trending faults. En-echelon folds in the Albert Formation adjacent to the Clover Hill Fault suggest dextral movement (Roberts 1990). Along the Clover Hill Fault southeast of Cedar Camp Brook, Albert Formation rocks in the hanging wall are juxtaposed against Mabou Group rocks in the footwall (Plate 1). Less than 10 km to the northeast, in the Donegal area, Mabou Group rocks in the hanging wall are juxtaposed against basement rocks in the footwall (Plate 1). It is difficult to explain this map relationship in terms of dip-slip displacement, and a post-Mabou strike-slip displacement of unknown sense is probably the best explanation. Although the magnitude of displacement cannot be determined, it need not be in excess of 5 km.

SUMMARY OF TECTONIC HISTORY

Based on the evidence presented above, the tectonic history of the western Moncton Subbasin is summarized as follows (see Figure 19):

1. Initiation of basin subsidence, in response to normal displacements on northeast- to east-trending faults, at least some of which were inherited Acadian structures. Deposition of the Horton Group was concurrent with this faulting.
2. Inversion of the basin following deposition of Horton Group rocks, resulting in northeast-trending folding and reverse/thrust faulting in Horton Group rocks and the consequent formation of the post-Horton unconformity.
3. Renewed extension during deposition of Moncton Group rocks on northeast to north-north-east trending faults. Variable displacements on faults led to local thickening of the Moncton Group section, for example in the Mill Brook area (Plate 1). The more rapidly subsiding areas eventually fell below sea level, resulting in Marine transgression and deposition of Windsor Group evaporites. The flooded areas remained below sea level until the regression of the Windsor sea during deposition of the Clover Hill Formation.
4. Regional uplift associated with the marine regression was accompanied by local subsidence and deposition of Mabou Group continental clastics that lie conformably on the marine Clover Hill Formation. Deposition of the Mabou Group was apparently a response to normal movement on northeast-trending master faults, resulting in the deposition of thick proximal fanglomerates.
5. The emplacement of the wedge structure associated with the Berry Mills Fault occurred during deposition of Mabou Group rocks, implying contraction during Mabou Group deposition. Some limited salt deformation also took place during Mabou Group deposition, as evidenced by the thinning of Mabou Group reflectors onto the salt structure recorded in seismic reflection profiles.
6. Syn-Mabou contraction culminated in the formation of the post-Mabou Group unconformity, followed by a period of regional thermal subsidence giving rise to a sag basin that was subsequently filled by Cumberland and Pictou Group rocks (e.g., St. Peter 1992, 1993).
7. Inversion of the basin following deposition of the Cumberland and Pictou groups, and localized in part within the Windsor salt. This basin inversion is associated with reverse movement on the Berry Mills, Urney, Clover Hill and possibly Gordon Falls faults and emplacement of the salt structures and reverse faults in cover rocks above the salt. This period of contraction probably corresponds to the Alleghenian orogeny (Ruitenberg and McCutcheon 1982).

DISCUSSION

IMPLICATIONS FOR TRAPPING MECHANISMS AND RESERVOIR POROSITY/PERMEABILITY

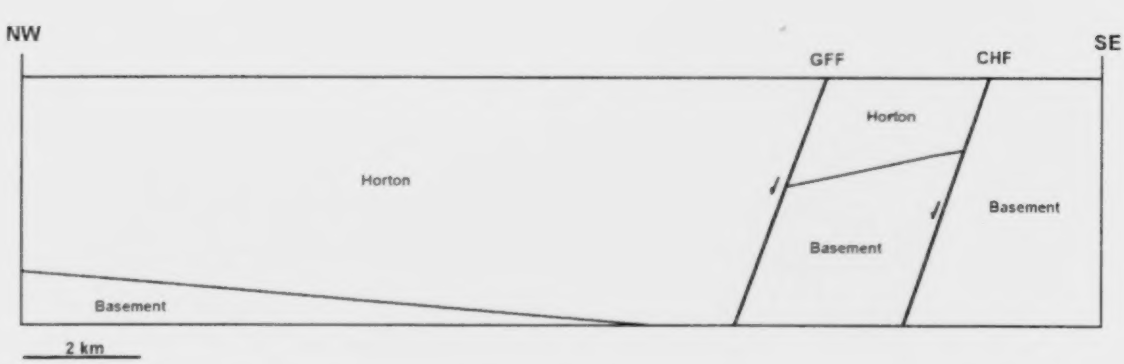
Studies of fault zones in hydrocarbon reservoirs have shown that faults may act as conduits or seals, or both, to fluids, including oil and gas (e.g., Caine et al. 1996; Knipe 1992). Faults act as conduits when they have an elevated permeability relative to their protolith, and as seals when they have a low permeability relative to their protolith. Elevated permeability may occur due to fracturing and/or brecciation resulting in dilatancy. Depressed permeability may result from the presence of emplaced fault-zone material formed by processes directly related to faulting. Those processes may be mechanical (e.g., cataclasis resulting in formation of impermeable clay gouge) or chemical (e.g., precipitation of veins or cement).

Caine et al. (1996) divided faults into four groups based on their permeability structure in terms of the presence or absence of a fault core and damage zone. 'Distributed conduit' type faults consist of a damage zone with no fault core; 'localized conduit' type faults typically consist of a single curviplanar surface with no development of a fault core or damage zone; 'combined conduit-barrier' type faults consist of a core of cataclastic material bounded by distributed zone of subsidiary structures; and 'localized barrier' type faults consist of well-developed cataclastic fault core with no damage zone. Observations of normal faults in the Albert Formation along Highway 1 show that fault zones affecting sandstone are generally of combined conduit-barrier type. The fault damage zone may have elevated permeabilty compared to protolith, but the fault core is composed of impermeable fault gouge. However, faults involving shale layers are generally of localized barrier type, having no damage zone and no significant elevation of permeability compared to their protolith The Hiram Brook Member in the McCully gas field is a unit of interbedded sandstone and grey shale and it is probable that faults within it are of the localized barrier or combined conduit-barrier type. Study of thin sections shows that fractures associated with faults are in general either healed with carbonate veins or filled with mechanically comminuted rock.

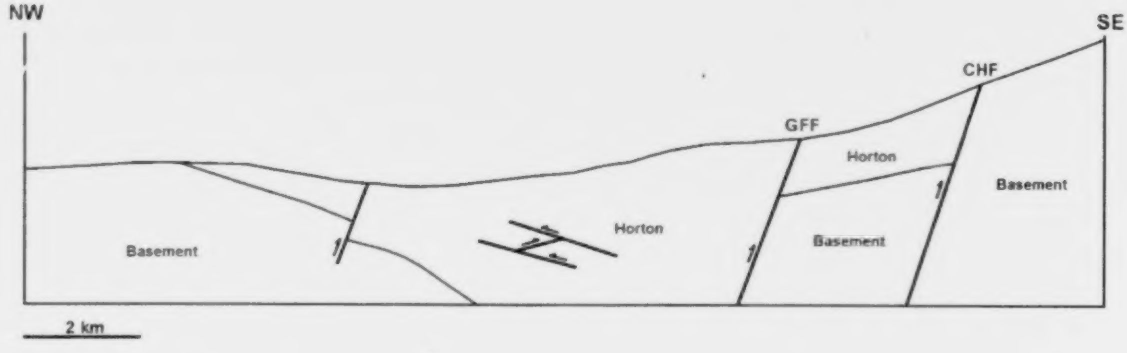
Studies of fluid flow behaviour in fault zones have suggested that permeability and porosity are only transiently elevated during brittle failure events, and are reduced to very low levels as precipitation of veins heals fracture networks (Byerlee 1993; Miller and Nur 2000). This healing takes place over time periods on the order of 1–1000 years (Bruhn et al. 1990). From this and the evidence presented above it is probable that minor faults within the McCully gas field are currently sealed and do not have significantly elevated porosity or permeability associated with them. However, it is likely that permeability is somewhat elevated compared to the protolith (which has very low permeability) because it is unlikely that all fractures are completely healed.

In major fault zones it is possible that complex folding patterns provide sites of elevated porosity and permeability. Along Highway 1 adjacent to the Kennebecasis River Fault, recumbent folds are observed (Figures 8b and 8c). The folds have broken hinges with no apparent healing by vein precipitation. The hinges are therefore sites of elevated fracture porosity and permeability. Observations of juxtaposed fold limbs with opposite younging directions also suggest the presence of tight to isoclinal folds, and the hinge zones of these folds may also be sites of elevated porosity

(a) Deposition of Horton Group, normal-sense movement on faults.


NW
GFF
CHF
SE
Horton
Horton
Basement
Basement
Basement
2 km

(b) Post-Horton basin inversion, uplift and erosion.


NW
SE
CHF
GFF
Horton
Basement
Horton
Basement
Basement
2 km

(c) Deposition of the Moncton Group associated with normal faulting and subsidence.

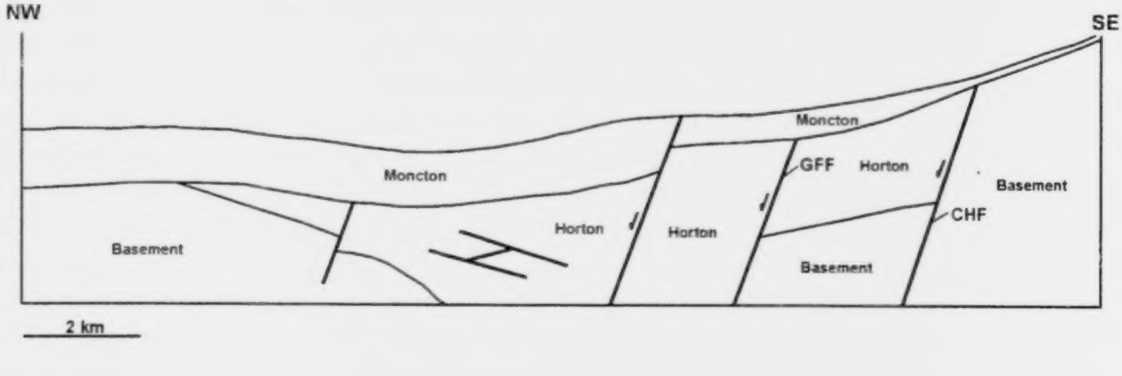
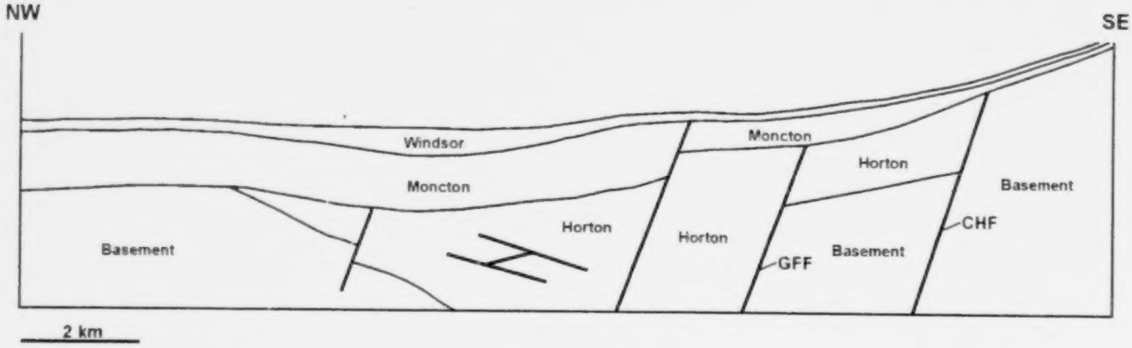
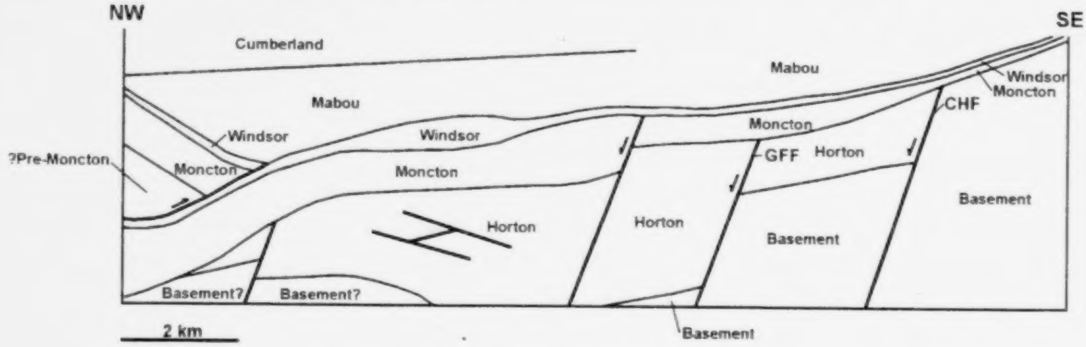

NW
SE
Moncton
GFF
Horton
Moncton
Basement
Horton
Horton
CHF
Basement
Basement
2 km

Figure 19. Model for the tectonic evolution of the McCully area.

(d) Continued subsidence, marine transgression, and deposition of Windsor Group evaporites.


NW
SE
Windsor
Moncton
Moncton
Horton
Basement
Horton
Horton
Basement
GFF
Basement
CHF
2 km

(e) Emplacement of tectonic wedge structure and formation of initial salt pillow during Mabou Group deposition. This was Followed by regional uplift, erosion and Cumberland Group deposition.


NW
SE
Cumberland
Mabou
Mabou
Windsor
Moncton
Windsor
Windsor
Moncton
Moncton
CHF
?Pre-Moncton
Moncton
Moncton
GFF
Horton
Horton
Horton
Basement
Basement
Basement?
Basement?
Basement
2 km

(f) Alleghanian contraction and basin inversion, with salt diapirism and reactivation of faults in reverse sense.

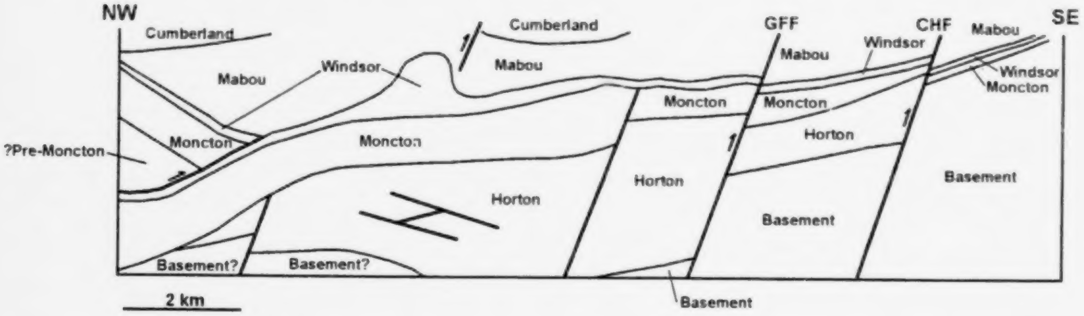

NW
Cumberland
Cumberland
GFF
CHF
Mabou
SE
Mabou
Windsor
Mabou
Mabou
Windsor
Windsor
Moncton
Moncton
Moncton
?Pre-Moncton
Moncton
Moncton
Horton
Horton
Horton
Basement
Basement
Basement?
Basement?
Basement
2 km

Figure 19. (Continued)

and permeability. Thus if there are major faults cutting the McCully gas field, these may provide sites of enhanced porosity and permeability associated with fault-related folds.

SALT TECTONICS

The asymmetry of the Penobsquis salt structure, the presence of thrust faults within the structure, and the spatial association of the structure with a major reverse fault in the salt cover favour formation of the structure through compressional tectonics. Numerous workers have discussed the possibility of regional contraction initiating or modifying salt structures (e.g., van Berkel et al. 1984; Jackson and Talbot 1986; Schwerdtner 1986, 1988; Talbot et al. 1988; Letouzey et al. 1995). Analogue modelling by Waltham (1997) shows that folding due to compression and drag by overburden moving over the salt may be more important than buoyancy or differential loading when salt layers are relatively thin (less than 300 m for the parameters used by Waltham). The asymmetry of the Penobsquis salt structure and the presence of overturned, southeast-vergent folds in its northeastern segment suggest that the salt overburden may have moved southeastward over the salt, with the salt body in its entirety acting as a distributed shear zone. It is speculated that the absence of extreme asymmetry in the southwestern segment of the salt structure may result from imposed boundary conditions that reflect narrowing of the salt basin to the southwest, i.e., the response of the salt to overburden drag may be different where the salt basin is very narrow.

There are other possible mechanisms for salt movement aside from compressional tectonics; they are: buoyancy, differential loading, gravity spreading and thermal convection (e.g., Jackson and Talbot 1986, 1994). These are rejected as important mechanisms for the formation of the Penobsquis salt structure for the following reasons:

Buoyancy. Because salt is relatively incompressible compared to other sediments, it tends to be less dense than overlying compacted sediments at depths of more than 1500 m or so (e.g., Jackson and Talbot 1986). This 'density inversion' leads to instability, and can force salt to flow upward, penetrating denser overlying sedimentary rocks until it reaches a 'level of neutral buoyancy' at a depth where the density of salt is equal to that of the surrounding rocks (e.g., Jackson and Talbot 1994). Numerous mathematical and physical model experiments have shown that where overburden has a finite yield strength, buoyancy is not an effective mechanism unless there is some initial relief in the top surface of the salt body (Jackson and Talbot 1986; Davison et al. 1993; Poliakov et al. 1993; Daudré and Cloetingh 1994). Jackson and Talbot (1986) estimated that the relief required is on the order of 150 m. They also noted that buoyancy becomes an increasingly important mechanism as salt structures grow in amplitude and overburden compacts to greater densities. Thus buoyancy is unlikely to initiate salt structures, but it may modify them when structures have initiated through other mechanisms.

Poliakov et al. (1996) suggested that salt overburdens can deform in both a brittle and viscous manner (see also Gratier et al. 1999). They used numerical modelling to demonstrate that buoyancy is sufficient to initiate salt structures when overburden deformation is accommodated by both pressure-solution creep and faulting. Their model suggests that buoyancy could have played some role in initiating salt deformation at Penobsquis, but it is not thought to be the main mechanism for two reasons. Firstly, the salt structure exhibits a pronounced asymmetry that is not expected where buoyancy is the main driving mechanism. Secondly, the timing of salt deformation (that is, after deposition of the Cumberland Group) shows that it did not initiate during burial of the salt by the Mabou and Cumberland groups, but rather during a later period of compression. It is possible that buoyancy played a role in modifying the salt structure when its relief exceeded 150 m or so (Jackson and Talbot 1986).

Differential loading. Jackson and Talbot (1986) used centrifugal experiments to suggest that natural examples of asymmetric salt structures formed through differential loading of the salt. Modelling by Ge et al. (1997) shows that the influence of a prograding wedge above the salt can initiate asymmetric salt anticlines that may then evolve into other kinds of salt structures. Progradation would result in the formation of a 'progressively steepening, landward facing limb of a salt-cored rolling monocline' (Ge et al. 1997). Several of the model results resemble the asymmetric shape of the Penobsquis salt structure. If a wedge composed of debris shedding from the Caledonia massif were prograding northwestward across the basin, this could partly explain the geometry of the Penobsquis evaporite body. Mabou Group strata would be an ideal candidate for that wedge. Seismic evidence shows that the Mabou group thins onto the salt ridge, indicating some syn-Mabou salt deformation. Hence it is concluded that differential loading due to progradation may have played a role in initiating the Penobsquis salt structure. It is also possible that early salt movement was a response to syn-Mabou contraction, as evidenced by emplacement of the structural wedge to the northwest of the salt structure (see above under Fault kinematics and timing). Differential loading probably did not play a significant role in the Alleghenian phase of salt movement, since there was no prograding sedimentary wedge at that time.

Gravity spreading. Gravity spreading does not result in the creation of relief in a salt body, rather it acts to dissipate relief in a salt body which lies above its level of neutral buoyancy (Jackson and Talbot 1986). It is unlikely that gravity spreading played any significant role in the formation of the Penobsquis salt structure. However, the overturned fold observed in the M–4A borehole (Figure 13c) may have resulted from the gravitational collapse of a salt structure that was originally somewhat taller.

Thermal convection. Thermal convection as a mechanism of salt movement (Talbot 1978; Jackson and Talbot 1986) arises because salt has a much higher thermal conductivity than surrounding rocks. It also has a high thermal expansivity. This will tend to guide heat flow into a salt structure or layer, and lead to density inversion and instability within the salt layer. Numerical modelling shows that a salt layer would have to be very thick, on the order of 4500 m (Jackson and Talbot 1986) or 1500 m (Talbot 1978), for thermal convection to be important in salt flow. It is unlikely that thermal convection played any significant role in the formation of the relatively thin Penobsquis salt structure. However, the presence of a salt structure would create significant thermal perturbations in the basin, possibly driving the circulation of fluids in faults above the salt structure, resulting in dissolution and formation of collapse breccia.

Based on the above arguments, the Penobsquis salt structure is interpreted to have a two-stage history. The structure initiated as a low-amplitude salt pillow during Mabou Group deposition, either as a result of syn-Mabou contraction or differential loading by a northwest-prograding wedge of Mabou Group fanglomerates. The initial salt pillow was modified into a high-amplitude salt wall during Alleghenian orogenesis. The Moncton Subbasin is therefore an example of an inverted, intracratonic salt basin (Letouzey et al. 1995). The salt wall was then modified by a combination of continued folding, differential loading through folding and faulting of the overburden, buoyancy forces, and drag resulting from overburden movement. Complex internal folding (e.g., Figure 13a) resulted from overprinting of the two phases of salt deformation coupled with the complex flow patterns typical during deformation of salt. Internal fold patterns differ in style from the overall geometry of the salt structure because the structure has been modified by dissolution and because the rheology of the salt differs from that of the surrounding rocks. Seismic evidence shows that the Macumber Formation below the salt ridge is unfaulted and deformation appears to have been entirely thin-skinned. The salt structure began to actively penetrate its overburden, resulting in normal and reverse faults above the salt structure (Davison et al. 1993; Schultz-Ela et al. 1993). These faults led to fluid circulation, possibly driven by high heat flow through the salt (Talbot 1978; Jackson and Talbot 1986), and dissolution of the salt resulting in solution collapse breccias.

FAULT KINEMATICS AND TECTONIC SETTING OF THE MONCTON SUBBASIN

Gussow (1953) identified four northeast-trending master fault systems in southern New Brunswick; the Belleisle, Berry Mills, Clover Hill and Harvey-Hopewell fault systems (Figure 2). The sense and timing of the movements on these and other Carboniferous faults in the Maritimes Basin has remained controversial. These faults have been described in all possible ways, i.e., as normal faults, reverse or thrust faults, and as sinistral or dextral strike-slip faults (Leger and Williams 1986). While much attention has been paid to large-scale tectonic models of basin development, important details of the sense and timing of fault movements, and their relationship to the overall tectonic history, have remained incompletely studied. The problem has been compounded by the lack of outcrop; the lack of adequate displacement markers; inadequate time constraints on fault movements; incomplete understanding of stratigraphy; and entrenched speculative hypotheses.

Basin initiation through dextral pull-apart, with the basin continuing to evolve in an overall wrench setting throughout the Carboniferous, has been proposed by several authors (Webb 1963,1969; Bradley 1982; Mosher and Rast 1984; Leger and Williams 1986; Nance and Warner 1986; Martel 1987; Nance 1987; St. Peter 1992, 1993).

Webb (1963, 1969) published estimates of offset of alluvial fans along the major faults, based on seismic and geological evidence. Webb proposed that southern New Brunswick had experienced a total dextral displacement of around 200 km, while the Dennis Beach Fault (Figure 2) had experienced a sinistral displacement of approximately 16 km, which may have been preceded by 80 km of dextral movement. Webb's displacement estimates have been largely discredited, and most subsequent workers have been more conservative in their estimates of strike-slip displacements. Van de Poll (1994) noted that Webb's estimates depended on the Mabou Group being made up of only one fan, a hypothesis that Van de Poll rejected.

Bradley (1982) suggested that unconformities or disconformities at different stratigraphic levels in different areas of the Maritime basin represented a single diachronous uplift event, occurring in response to changing stress conditions as blocks were moved along major strike-slip faults. The evidence presented in the present study shows that the Carboniferous history of the basin is characterized by repeated cycles of deposition, punctuated by unconformities or disconformities related to basin inversion. It is argued that the unconformities and disconformities are basin-wide phenomena, and are related to discrete uplift events, rather than a single diachronous event related to strike-slip tectonics. For the basin to have experienced several strike-slip related rifting and inversion events, there would presumably have to be very large displacements along strike-slip faults, carrying the basin into extensional or contractional environments at releasing or restraining bends (Woodcock and Fischer 1986; Woodcock and Schubert 1994). There is no good evidence for strike-slip displacements of this magnitude in the Moncton Subbasin.

Flower structures (Harding 1985) have been recognized by Webb (1963, 1969), St. Peter (1992, 1993) and Wilson (2002). Flower structures indicate some, but not necessarily large amounts, of strike-slip, nor does the presence of such structures require that the basin formed as a pull-apart basin. Interpretations of seismic reflection profiles from the Hillsborough area (Figure 2; Wilson 2002) show the major faults rooting into a low-angle detachment at depth, suggesting a more important role for dip-slip than strike-slip tectonics in the Hillsborough area.

Leger and Williams (1986) noted that there was 'no cogent evidence' for significant Carboniferous strike-slip movement in southern New Brunswick. However, they concluded that Carboniferous faulting in New Brunswick was primarily transcurrent, with related vertical movements, on the basis of a comparison with Newfoundland, where there is a strong component of brittle strike-slip along northeast-trending faults (Leger and Williams 1986).

Martel (1987) noted that rapid subsidence took place during the initial opening of the Moncton Subbasin, leading to perennial lake conditions as subsidence outpaced sedimentation. Rapid subsidence is typical of small pull-apart basins. However, this is not the only possible explanation for the rapid initial subsidence. Nickerson (1994) discussed the formation of the Maritimes Basin through extensional collapse of the Acadian orogen in the late Devonian, in which case extension and subsidence would likely be rapid in the early stages (Dewey 1988).

Several authors have discussed the existence of a fold-thrust belt in southern New Brunswick, spatially associated with a major restraining bend in the dextral Cobequid-Chedabucto Fault system (Mosher and Rast 1982; Nance and Warner 1986; Nance 1987). Under imposed northwest-southeast tectonic compression, the east-trending Cobequid-Chedabucto Fault would be active as a dextral strike-slip fault, but northeast-trending faults in the Moncton Subbasin would be active as reverse or thrust faults. It is impossible to determine how much deformation in the Moncton Subbasin resulted from local compression associated with a major restraining bend in the Cobequid-Chedabucto Fault system, and how much resulted from the imposed regional tectonic stress. In any case, a wrench setting for the basin does not seem necessary.

The long, straight nature of the faults in the Maritimes Basin has been proposed as evidence that those faults have carried significant strike-slip movement (e.g., Wilson 1962; Nickerson 1994). It is possible that some of the master faults in the Moncton Subbasin are long and straight because they are strike-slip faults. However, it seems equally likely that this is a result of the reactivation of pre-Carboniferous strike-slip structures (Leger and Williams 1986). It is also worth noting that some of the major faults, notably the Clover Hill-Caledonia Fault system (Figure 2), are not through-going or particularly straight.

It is clear from the above discussion that no good evidence demonstrating extensive Carboniferous strike-slip movements on Faults in the Moncton Subbasin has ever been presented. Evidence from both the Hillsborough and McCully areas shows that strike-slip displacements along northeast-trending faults are small (Wilson 2002; this study). Evidence presented in favour of an overall wrench setting for the basin has been in general circumstantial and open to other interpretations, and new evidence is beginning to emerge (Nickerson 1994; this study) to suggest that other interpretations must be considered.

Nickerson (1994) noted that Horton sedimentation in the Elgin area was accompanied by a 3 km southwest migration of the basin depocentre. Nickerson explains this as the result of a limited component of dextral strike-slip movement on the basin-bounding fault system, and used this as evidence that a 'mixed-mode' oblique-slip model for the initiation of sedimentation in the Moncton Subbasin was more likely than a strike-slip pull-apart model. Evidence from this study that vertical movements are important supports that contention. Nickerson (1994) also suggested that the initial rapid subsidence leading to perennial lake conditions in the basin might be explained by gravitational collapse of the Acadian orogen, rather than externally imposed tectonic forces. The initial phase of rapid basin subsidence terminated during a period of dextral transpressive tectonics, with dextral wrench tectonics continuing 'for the remainder of the Carboniferous era'. Recent observations in the Hillsborough area (Wilson 2002) indicate that post-Windsor strike-slip displacements are small, but the initiation of the Moncton Subbasin through gravitational collapse of the Acadian orogen remains a possibility.

Evidence suggests that while strike-slip movements on Carboniferous northeast-trending faults have undoubtedly occurred in New Brunswick, the basin did not form or evolve in an overall wrench setting. In southern New Brunswick, many of the major faults activated in the Carboniferous are inherited Acadian structures (e.g., Leger and Williams 1986). Obliquity of movement along the faults during the Carboniferous, leading to strike-slip displacements, is to be expected, since extension or compression is unlikely to be precisely orthogonal to pre-existing structures. It is concluded that strike-slip movements have occurred on basin-controlling faults, but that the basin is primarily a mixed-mode depocentre that evolved in an oblique-slip setting.

MESOZOIC DEFORMATION

It has been suggested that deformation of the Windsor Group evaporites in the Cassidy Lake area occurred in response to Mesozoic extension (Roberts 1990; Roberts and Williams 1993). Roberts and Williams (1993) pointed out that the evaporites at Cassidy Lake area had all the characteristics of a subhorizontal mylonite zone. They contended that this is not in agreement with a Carboniferous age of evaporite deformation because movement on subvertical faults was occurring in the Maritimes Basin at that time. The evidence presented in this study shows that deformation in the Penobsquis evaporite body occurred in two stages; first during Mabou Group deposition, and second as a response to a period of contraction, most probably during the Alleghenian. A Mesozoic extensional origin for the Penobsquis salt structure is considered unlikely.

Fault movements that are younger than Westphalian are poorly constrained in the Maritimes Basin and limited Mesozoic deformation cannot be ruled out. Study of published maps in the Hillsborough area reveals both dextral and sinistral displacements of Windsor Group rocks, and sinistral displacement of Cumberland Group rocks, which are the youngest rocks in the area (St. Peter 1992; St. Peter and Johnson 1997; Wilson 2002). It was tentatively concluded (Wilson 2002) that initial dextral displacement along the faults was partly or completely recovered by later sinistral movement, with the magnitude of sinistral displacement on individual faults increasing toward the southeast. This is partly supported by Wang and Ludman (2002), who noted a period of dextral slip followed by sinistral movement along the Norumbega Fault in eastern Maine during the Carboniferous. According to Olsen and Schlische (1990), the east-trending Cobequid-Chedabucto Fault was reactivated as a sinistral strike-slip fault in the Mesozoic, while northeast-trending structures in southern New Brunswick were reactivated as normal faults (Plint and van de Poll 1984). Thus it is possible that late sinistral displacements on east-north-east trending structures in the Hillsborough area are Mesozoic in age, and that northeast-trending faults in the McCully area have experienced some Mesozoic normal movement. The Cretaceous sediments of the Vinegar Hill Formation occur adjacent to the Clover Hill Fault at Cassidy Lake, south of Sussex (Figure 2), and may be analogous to half-graben controlled Cretaceous deposits in Nova Scotia (Stea and Pullan 2001). Apatite fission-track data from Maine suggest that the Norumbega-Fredericton Fault also experienced significant dip-slip displacements in Cretaceous time (West and Roden-Tice 2003). Withjack et al. (1995) provided evidence that the Mesozoic Fundy basin had experienced both extension and later contraction in the Mesozoic. Thus it is possible that Mesozoic events have left some imprint on the structural configuration of the Maritimes Basin in New Brunswick.

CONCLUSIONS AND RECOMMENDATIONS

1.The pre-Windsor Group stratigraphy requires revision. The post-Acadian, pre-Windsor section in this area is divided into two groups. The basal Horton Group comprises Memramcook, Albert and 'lower redbed' formations, and is unconformably overlain by the Moncton Group, which consists of the Round Hill, Weldon and Hillsborough formations.

2. The McCully gas field is a northeast-trending anticlinal structure approximately 5 km wide and 12 km long. It is partially truncated by the pre-Sussex Group unconformity. The trap is thought to be a combination anticline/unconformity. It is possible that faults play a role in trapping. Minor faults in the gas field may be associated with elevated permeability relative to the protolith, although permeability is unlikely to be very high. Enhanced porosity and permeability may also occur in the hinge areas of fault-related folds in major fault zones.

3. In the McCully gas field, seismic interpretations suggest that Albert Formation strata contain low-angle thrust faults and northeast-trending folds at a variety of scales. Most minor faults observed in outcrop are normal in sense and trend approximately northwest, although some faults with strike-slip components of movement do occur. Close to major faults tight to isoclinal folds with broken hinges are observed. Intraformational folded and boudinaged layers in the Albert Formation are synsedimentary gravity slump structures; they may have been triggered by earthquake activity during early basin extension and subsidence.

4. The Penobsquis salt structure is an elongate, asymmetric salt ridge that is divided into two segments. The southwestern segment trends at 055° and is slightly asymmetric and southeast-vergent. The northeastern segment trends 070° and is overturned to recumbent and southeast vergent. The distribution of potash deposits in the main salt structure are fold-controlled, while those in the smaller structure to the southeast are shear-zone controlled. The southeast-vergent asymmetry and northeast-trend of the salt structure, the association with northeast-trending reverse faults in the salt cover, and the presence of internal low-angle reverse faults, suggest that the salt structure formed during a period of regional NW–SE contraction. The thinning of Mabou Group reflectors onto the salt structure recorded in seismic reflection profiles demonstrates that salt deformation initiated during Mabou Group deposition. Cumberland Group rocks are folded above the salt structure, and salt-linked faults cut Cumberland Group rocks, demonstrating that the main phase of salt deformation occurred after deposition of Cumberland Group rocks (Westphalian A). Regional considerations indicate that main phase of salt tectonics occurred during Alleghenian compression, in the late Carboniferous or early Permian. The Moncton Subbasin is therefore an example of an inverted intracratonic salt basin.

5. The wedge-shaped structure imaged on seismic lines immediately to the southeast of the Berry Mills Fault may contain Moncton Group lying upon Horton Group rocks, or Moncton Group rocks may lie directly upon basement. If Albert Formation rocks exist in the wedge, duplex and backthrust structures interpreted from seismic reflection profiles in the wedge toe may provide traps for hydrocarbon accumulations.

6. Seven tectonic events are cited as significantly contributing to the evolution of the Moncton Subbasin: (1) an initial period of basin subsidence; (2) post-Horton Group inversion; (3) syn-Sussex Group extension, leading to subsidence, marine transgression and deposition of Windsor Group evaporites; (4) regional uplift leading to marine regression accompanied by localized extension and deposition of Mabou Group continental clastics; (5) tectonic emplacement of the wedge structure to the southeast of the Berry Mills Fault and early salt deformation, apparently culminating in a period of basin-wide uplift and erosion marked by a major unconformity between the Mabou and Cumberland groups; (6) a thermal sag phase resulting in subsidence that accommodated deposition of the distal fluvial strata of the Cumberland and Pictou groups; and finally, (7) Alleghenian (late Carboniferous and/or Permian) basin inversion and salt tectonics. In other words, the tectonic history of the Moncton Subbasin is characterized by cycles of deposition which are punctuated by unconformities related to uplift and basin inversion. While strike-slip movements (both sinistral and dextral) have undoubtedly occurred in the Moncton Subbasin, they are viewed as less important, in terms of basin evolution, than dip-slip displacements. A mixed-mode, oblique-slip model for the tectonic setting of the Moncton Subbasin is considered to be more realistic than a strike-slip model.

7. Mesozoic events documented from other parts of the Maritimes Basin suggest that Mesozoic tectonism may have had significant effects on the Moncton Subbasin. Further work, including age-dating of fault rocks and fission track analysis, should be undertaken to explore this possibility.

REFERENCES

Anderle, J.P., Crosby, K.S., and Waugh, D.C.E. 1979. Potash at Salt Springs, New Brunswick. Economic Geology, **74**: 389–396.

Barr, S.M., and White, C.E. 1996. Contrasts in late Precambrian—early Paleozoic tectonothermal history between Avalon composite terrane sensu stricto and the other possible peri-Gondwanan terranes in southern New Brunswick and Cape Breton Island, Canada. *In* Avalonian and related peri-Gondwanan terranes of the circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Survey of America Special Paper, **304**: 95–108.

Bell, W.A. 1929. Horton-Windsor district, Nova Scotia. Geological Survey of Canada Memoir, **155**: 268 p.

Bradley, D.C. 1982. Subsidence in Late Paleozoic basins in the northern Appalachians. Tectonics, **1**: 107–123.

Bradley, D., and Hanson, L. 1998. Paleoslope analysis of slump folds in the Devonian Flysch of Maine. Journal of Geology, **106**: 305–318.

Bruhn, R.L., Yonkee, W.A., and Parry, W.T. Structural and fluid-chemical properties of seismogenic normal faults. Tectonophysics, **175**: 139–157.

Byerlee, J. 1993. Model for episodic flow of high-pressure water in fault zones before earthquakes. Geology, **21**: 303–306.

Caine, J.S., Evans, J.P., and Forster, C.B. 1996. Fault zone architecture and permeability structure. Geology, **24**: 1025–1028.

Carr, F.A. 1968. Stratigraphy and spore assemblages, Moncton map area, New Brunswick. Geological Survey of Canada Paper 67–29, 47 p.

Carter, D.C., and Pickerill, R.K. 1985a. Algal swamp, marginal and shallow evaporitic lacustrine lithofacies from the Late Devonian-Early Carboniferous Albert Formation, southeast New Brunswick, Canada. Maritime Sediments and Atlantic Geology, **21**: 69–86.

Carter, D.C., and Pickerill, R.K. 1985b. Lithostratigraphy of the Late Devonian-Early Carboniferous Horton Group of the Moncton Subbasin, southern New Brunswick. Maritime Sediments and Atlantic Geology, **21**: 11–24.

Crosby, K.S., and Waugh, D.C.E. 1975. Limestone and gypsum investigations in southeastern New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Topical Report 75–10.

Daudré, B., and Cloetingh, S. 1994. Numerical modelling of salt diapirism: influence of the tectonic regime. Tectonophysics, **240**: 59–79.

Davison, I., Insley, M., Harper, M., Weston, P., Blundell, D., McClay, K., and Quallington, A. 1993. Physical modelling of overburden deformation around salt diapirs. Tectonophysics, **228**: 255–274.

Dewey, J.F. 1988. Extensional collapse of orogens. Tectonics, **7**: 1123–1139.

Dickie, D.E. 1977. Confidential log of PCA #10 (B–3) borehole. Held in confidential lease files with the New Brunswick Department of Natural Resources.

Durling, P., and Howells, K. 2002. Gravity and seismic interpretations for some Maritime Carboniferous basins; implications for Upper Carboniferous basin development [abstract]. Atlantic Geology, **38**: 81.

Durling, P., and Martel, T. 2003. The McCully gas field: A proven resource with high exploration potential. Geological Society of America Abstracts With Programs, **35**, No. 3: p. 81.

Foley, S.L. 1989. Geology of the Stoney Creek oil and gas field, and its implications for the tectonic evolution of the eastern Moncton subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report 89–1.

Garnett, J.A., and Brown, R.L. 1973. Fabric variation in the Lubec-Belleisle zone of southern New Brunswick. Canadian Journal of Earth Science, **10**: 1591–1599.

Ge, H., Jackson, M.P.A., and Vendeville, B.C. 1997. Kinematics and dynamics of salt tectonics driven by progradation. American Association of Petroleum Geologists Bulletin, **81**: 398–423.

Geldsetzer, H.H.J. 1978. The Windsor Group in Atlantic Canada—an update. *In* Current Research, Part C. Geological Survey of Canada Paper 78–1C, 43–48.

Giles, K.A. and Lawton, T.F. 1999. Attributes and evolution of an exhumed salt weld, La Popa basin, northeastern Mexico. Geology, **27**: 323–326.

Gratier, J.P., Renard, F., and Labaume, P. 1999. How pressure solution creep and fracturing processes interact in the upper crust to make it behave in both a brittle and viscous manner. Journal of Structural Geology, **21**: 1189–1197.

Greiner, H.R. 1962. Facies and sedimentary environments of Albert shale, New Brunswick. American Association of Petroleum Geologists Bulletin, **69**: 767–780.

Greiner, H.R. 1974. The Albert Formation of New Brunswick: a Palaeozoic lacustrine model. Geologische Rundschau, **63**: 1102–1113.

Gussow, W.C. 1953. Carboniferous stratigraphy and structural geology of New Brunswick, Canada. American Association of Petroleum Geologists Bulletin, **37**: 1713–1816

Hamilton, J.B. 1961. Salt in New Brunswick. New Brunswick Department of Lands and Mines, Mines Branch, Mineral Resource Report No.1, 73 p.

Harding, T.P. 1985. Seismic characteristics and identification of negative flower structures, positive flower structures, and positive structural inversion. American Association of Petroleum Geologists Bulletin, **69**: 582–600.

Howie, R.D. 1988. Upper Palaeozoic evaporites of southeastern Canada. Geological Survey of Canada Bulletin, **380**: 120 p.

Hubbert, M.K. 1953. Entrapment of petroleum under hydrothermal conditions. American Association of Petroleum Geologists Bulletin, **37**: 1954–2026.

Jackson, M.P.A., and Talbot, C.J. 1986. External shapes, strain rates, and dynamics of salt structures. Geological Society of America Bulletin, **97**: 305–323.

Jackson, M.P.A., and Talbot, C.J. 1994. Advances in salt tectonics. *In* Continental Deformation. *Edited by* P.L. Hancock. Pergamon Press, New York. pp. 159–179.

Jenyon, M.K. 1986. Salt Tectonics. Elsevier, New York. 191 p.

Johnson, S.C. 1995. A preliminary report on the stratigraphy of Late Namurian to Stephanian fluviatile strata in southeastern New Brunswick. *In* Current Research 1995–E; Geological Survey of Canada, pp. 313–320.

Keighley, D.G. 2005. Geology of the Case Syncline area, part of NTS 21 H/12. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Mineral Resource Report (in preparation).

Kingston, P.W., and Dickie, D.E. 1979. Geology of New Brunswick potash deposits. Canadian Institute of Mining and Metallurgy Bulletin, **72**: 134–147.

Knipe, R.J. 1992. Faulting processes and fault seal. *In* Structural and Tectonic Modelling and its Application to Petroleum Geology. *Edited by* R.M. Larsen, H. Brekke, B.T. Larsen and E. Talleraas. Norwegian Petroleum Society Special Publication, **1**: 325–342.

Leger, A., and Williams, P.F. 1986. Transcurrent faulting history of southern New Brunswick. *In* Current Research, Part B. Geological Survey of Canada, Paper 86–1B, pp. 111–120.

LeTouzey, J.B., Colletta, R., Vially, R., and Chermette, J.C. 1995. Evolution of salt-related structures in compressional settings. *In* Salt Tectonics: A Global Perspective. *Edited by* M.P.A. Jackson, D.G. Roberts, and S. Snelson. American Association of Petroleum Geologists Memoir, **65**: 41–60.

Lynch, G. 1999. Shell Canada Limited Albert oil shales geological results from slim hole drilling program, 1998–1999. Shell Canada Ltd., 33 p.

Macauley, G., Ball, F.D., and Powell, T.G. 1984. A review of the Carboniferous Albert Formation oil shales, New Brunswick. Bulletin of Canadian Petroleum Geology, **32**: 27–37.

Martel, A.T. 1987. Seismic stratigraphy and hydrocarbon potential of the strike-slip Sackville Subbasin, New Brunswick. *In* Sedimentary Basins and Basin-Forming Mechanisms. *Edited by* C. Beaumont and A.J. Tankard. Canadian Society of Petroleum Geologists Memoir, **12**: 319–334.

McCutcheon, S.R. 1978. Geology of the Apohaqui-Markhamville area, map area R–25 (21H/11W, 21H/12E). New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 78–5, 41 p.

McCutcheon, S.R. 1981. Stratigraphy and paleogeography of the Windsor Group in southern New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Division Open File 81–31. 210 p.

McCutcheon, S.R., and Robinson, P.T. 1987. Geological constraints on the genesis of the Maritimes Basin, Atlantic Canada. *In* Sedimentary Basins and Basin-Forming Mechanisms. *Edited by* C. Beaumont and A.J. Tankard. Canadian Society of Petroleum Geologists Memoir, **12**: 287–297.

McLeod, M.J. 1980. Geology and mineral deposits of the Hillsborough area map-area V–22 and V–23 (parts of 21 H/15E and 21 H/15W). New Brunswick Depaartment of Natural Resources, Mineral Resources Division, Map Report 79–6, 35 p.

Miller, S.A., and Nur, A. 2000. Permeability as a toggle switch in fluid-controlled crustal processes. Earth and Planetary Science Letters, **183**: 133–146.

Mosher, S., and Rast, N. 1984. The deformation and metamorphism of Carboniferous rocks in Maritime Canada and New England. *In* Variscan Tectonics of the North Atlantic Region. *Edited by* D.H.W. Hutton and D.J. Sanderson. Geological Society of London Special Publication, **14**: 233–244.

Nance, R.D. 1987. Dextral transpression and Late Carboniferous sedimentation in the Fundy coastal zone of southern New Brunswick. Canadian Society of Petroleum Geologists Memoir, **12**: 363–377.

Nance, R.D., and Warner, J.B. 1986. Variscan tectonostratigraphy of the Mispec Group, southern New Brunswick: Structural geometry and deformational history. *In* Current Research, part A. Geological Survey of Canada, Paper 86–1A, pp. 351–358.

Nickerson, W.A. 1994. Geophysical constraints on the stratigraphy, structure and tectonic evolution of the Late Devonian/Carboniferous Moncton subbasin, New Brunswick. Unpublished Ph.D thesis, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador, 306 p.

Norman, G.W.H. 1941a. Moncton, Westmorland and Albert Counties, New Brunswick. Geological Survey of Canada, Map 646A with descriptive notes.

Norman, G.W.H. 1941b. Hillsborough, Albert and Westmorland Counties, New Brunswick. Geological Survey of Canada, Map 647A with descriptive notes.

Olsen, P.E., and Schlische, R.W. 1990. Transtensional arm of the early Mesozoic Fundy rift basin: Penecontemporaneous faulting and sedimentation. Geology, **18**: 695–698.

Passchier, C.W. 1984. The generation of ductile and brittle shear bands in a low-angle mylonite zone. Journal of Structural Geology, **6**: 273–281.

Plint, A.G., and van de Poll, H.W. 1984. Structural and sedimentary history of the Quaco Head area, southern New Brunswick. Canadian Journal of Earth Science, **21**: 753–761.

Poliakov, A.N.B., Podladchikov, Y., and Talbot, C. 1993. Initiation of salt diapirs with frictional overburdens: numerical experiments. Tectonophysics, **228**: 199–210.

Poliakov, A.N.B., Podladchikov, Y., Dawson, E.C., and Talbot, C. 1996. Salt diapirism with simultaneous brittle faulting and viscous flow. *In* Salt Tectonics. *Edited by* G.I. Alsop, D.J. Blundell and I. Davison. Geological Society of London Special Publication, **100**: 291–302.

Roberts, W. 1990. A structural analysis of the Denison Potacan sylvinite ore body, Clover Hill, New Brunswick, Canada. Unpublished MSc thesis, University of New Brunswick, Fredericton, New Brunswick. 312 p.

Roberts, W., and Williams, P.F. 1993. Evidence for early Mesozoic extensional faulting in Carboniferous rocks, southern New Brunswick, Canada. Canadian Journal of Earth Science, **30**: 1324–1331.

Roliff, W.A. 1955. Exploration for oil and gas in eastern Canada. Proceedings of the Geological Association of Canada, **7**: 61–81.

Roulston, B.V., and Waugh, D.C.E. 1981. A borate mineral assemblage from the Penobsquis and Salt Springs evaporite deposits of southern New Brunswick. Canadian Mineralogist, **19**: 291–301.

Roulston, B.V., and Waugh, D.C.E. 1985. Stratigraphic comparison of the Mississippian potash deposits in New Brunswick, Canada. *In* Sixth International Symposium on Salt, volume 6. *Edited by* B.C. Schreiber and H.L. Harner. pp. 115–129.

Ruitenberg, A.A., and McCutcheon, S.R. 1982. Acadian and Hercynian structural evolution of New Brunswick. *In* Major Structural Zones and faults of the Northern Appalachians. *Edited by* P. St-Julien and J. Beland. Geological Association of Canada Special Paper 24, 117–148.

Schultz-Ela, D.D., Jackson, M.P.A., and Vendeville, B.C. 1993. Mechanics of active salt diapirism. Tectonophysics, **228**: 275–312.

Schwerdtner, W.M. 1986. Identification of evaporite diapirs formed under the influence of horizontal compression. Bulletin of Canadian Petroleum Geology, **34**: 271–276.

Schwerdtner, W.M. 1988. Identification of evaporite diapirs formed under the influence of horizontal compression: Reply. Bulletin of Canadian Petroleum Geology, **36**: 94–95.

Smith, D.A. 1966. Theoretical considerations of sealing and non-sealing faults. American Association of Petroleum Geologists Bulletin, **50**: 363–374.

Smith, D.A. 1980. Sealing and nonsealing faults in Louisiana Gulf coast salt basin. American Association of Petroleum Geologists Bulletin, **64**: 145–172.

Stea, R.R., and Pullan, S.E. 2001. Hidden Cretaceous basins in Nova Scotia. Canadian Journal of Earth Science, **38**: 1335–1354.

St. Peter, C. 1992. Lithologic facies, seismic facies, and strike-slip setting of the Lower Carboniferous alluvial/fluvial/lacustrine Albert Formation of New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 229 p.

St. Peter, C. 1993. Maritimes Basin evolution: Key geologic and seismic evidence from the Moncton Subbasin of New Brunswick. Atlantic Geology **29**: 233–270.

St. Peter, C. 1995. Upper Devonian/Carboniferous bedrock geology of the Wards Creek and Sussex area (parts of 21 H/11 and 21 H/12). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Map Plate 94–10B (revised 2003).

St. Peter, C. 2001. Petroleum geology in the Carboniferous of southeastern New Brunswick. *In* New England Intercollegiate Geology Conference, Guidebook to Field Trips in New Brunswick and Western Maine. *Edited by* R.K. Pickerill and D. Lentz. pp. A4–1 – A4–30.

St. Peter, C. 2002. Bedrock geology of the McCully natural gas field area, Moncton Subbasin (parts of NTS 21 H/11, 12, 13 and 14), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2002–33.

St. Peter, C., and Johnson, S.C. 1997. Carboniferous geology of the Hillsborough area (NTS 21 H/15), Albert and Westmorland counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97–8 (revised 2000).

Talbot, C.J. 1978. Halokinesis and thermal convection. Nature, **273**: 739–741.

Talbot, C.J., Koyi, H., Sokoutis, D., and Mulugeta, G. 1988. Identification of evaporite diapirs formed under the influence of horizontal compression: A discussion. Bulletin of Canadian Petroleum Geology, **36**: 91–94.

van Berkel, J.T., Schwerdtner, W.M., and Torrance, J.G. 1984. Wall-and-basin structure: An intriguing tectonic prototype in the central Sverdrup Basin, Canadian Arctic Archipelago. Bulletin of Canadian Petroleum Geology, **32**: 343–358.

van de Poll, H.W. 1994. Carboniferous provenance and lithostratigraphy of the Chignecto Bay region, New Brunswick: A preliminary assessment. *In* Current Research 1993. *Edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 12, pp. 188–201.

van de Poll, H.W. 1995. Upper Paleozoic rocks: New Brunswick, Prince Edward Island and Îles de la Madeleine. *In* Chapter 5 of Geology of the Appalachian-Caledonian orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, No. 6, pp. 455–492.

Waltham, D. 1997. Why does salt start to move? Tectonophysics, **282**: 117–128.

Wang, C., and Ludman, A. 2002. Evidence for post-Acadian through Alleghenian deformation in eastern Maine: multiple brittle reactivation of the Norumbega Fault system. Atlantic Geology, **38**: 37–52.

Webb, G.W. 1963. Occurrence and exploration significance of strike-slip faults in southern New Brunswick, Canada. Bulletin of the American Association of Petroleum Geologists, **47**: 1904–1927.

Webb, G.W. 1969. Palaeozoic wrench faults in Canadian Appalachians. American Association of Petroleum Geologists Memoir, **12**: 754–786.

West, D.P., and Roden-tice, M.K. 2003. Late cretaceous reactivation of the Norumbega fault zone, Maine: Evidence from apatite fission-track ages. Geology, **31**: 649–652.

Williams, E.P. 1974. Geology and petroleum possibilities in and around the Gulf of St. Lawrence. American Association of Petroleum Geologists Bulletin, **58**: 1137–1155.

Williams, H.1979. Appalachian orogen in Canada. Canadian Journal of Earth Sciences, **16**: 792–807.

Wilson, J.T. 1962. Cabot fault, an Appalachian equivalent of the San Andreas and Great Glen faults and some implications for continental displacement. Nature, **195**: 135–138.

Wilson, P. 2002. Structural geology of the Albert Mines—Taylor Village area, southeastern New Brunswick. *In* Current Research, 2001. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy; Minerals, Policy and Planning Division; Mineral Resource Report 2002–4, 129–153.

Wilson, P. 2003. Stratigraphy, evaporite structure and tectonic history in the McCully area, southern New Brunswick: Preliminary results. *In* Current Research 2002. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division; Mineral Resource Report 2003–4, pp. 101–121.

Withjack, M.A., Olsen, P.E., and Schlische, R.W. 1995. Tectonic evolution of the Fundy rift basin, Canada: Evidence of extension and shortening during passive margin development. Tectonics, **14**: 390–405.

Woodcock, N.H., and Fischer, M. 1986. Strike-slip duplexes. Journal of Structural Geology, **8**: 725–735.

Woodcock, N.H., and Schubert, C. 1994. Continental strike-slip tectonics. *In* Continental Deformation. *Edited by* P.L. Hancock. Pergamon Press, Oxford, pp. 251–263.

APPENDIX 1

Summary Logs of Salt Cores

Potash Company of America B-3
Summary Log

Commence logging at 304.05 m

304.05-307.44 m:	UPPER HALITE [banded subunit]. Purple argillaceous halite with laminae of grey clay. Dip 25°.
307.44-323.50 m:	ORE ZONE. Fine- to medium-grained sylvite 10%, with coarse-grained, clear halite, significant blue halite, and disseminated grey-green clay. Strong compositional layering, clean halite/sylvite, blue halite and clay, dipping 20°.
323.50-336.45 m:	ORE ZONE [lower gradational zone]. Orange, clean halite with blebs of grey-green clay, and scattered fine-grained crystals of sylvite. Schistosity dips 20°-30°.
336.45-403.18 m:	MIDDLE HALITE [red-brown subunit]. Red-purple, argillaceous and anhydritic halite with bands of pale to deep orange, clean halite up to 20 cm thick. Schistosity dipping 20°, subparallel to the primary layering.
403.18-416.16 m:	ORE ZONE [lower gradational zone]. Coarse, pale orange clean halite with trace scattered sylvite crystals, interbanded with argillaceous sylvinite. Bands on order of 1 cm thick. Schistosity and/or compositional layering dips 25°.
416.16-422.42 m:	ORE ZONE. As described for 307.44-323.50 m.
422.42-445.85 m:	ORE ZONE [lower gradational zone]. As described for 403.18-416.16 m.
445.85-458.69 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite with 10 cm bands of pale orange to orange clean halite. Some borate aggregates and anhydrite blebs. Schistosity dips 35°.
458.69-468.84 m:	ORE ZONE [lower gradational zone]. As described for 403.18-416.16 m, but with coarse to very coarse, red-rimmed, transparent sylvite crystals at some horizons. Some disseminated grey-green clay. Schistosity dips 35°.
468.84-479.76 m:	ORE ZONE. Sylvinite as described for 307.44-323.50 m.
479.76-501.70 m:	ORE ZONE [lower gradational zone]. As described for 403.18-416.16 m. Schistosity steepening from 35°-40° at top, to 45°-50° at base.
501.70-543.40 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite with significant sylvite. Dip of schistosity 45°-50°, subparallel to dip of primary layering.
543.40-552.79 m:	MIDDLE HALITE [grey-green subunit]. Red-brown argillaceous halite with significant grey-green clay. Schistosity dips approximately 50°, parallel to sharp lower contact.
552.79-637.82 m:	BASAL HALITE. Coarse to very coarse, clean to slightly anhydritic halite gives way to coarse-grained, clean schistose halite (Figure 8a). Dip of

schistosity near top is 45°-50°, parallel to primary layering. The schistosity becomes more pervasive downward; schistose halite grades downward into coarse-grained halite crystals in a fine-grained schistose halite matrix, and finally into coarse-grained halite with 10-20° dipping, cm-scale, bands of fine-grained, anhydritic halite over the basal 10 m.

637.82-642.17 m: CORE MISSING

642.17-648.08 m: BASAL ANHYDRITE. Grey, finely laminated anhydrite and limestone. Fractures in limestone contain halite veins. Laminae dip 15°.

TOTAL DEPTH

Potash Company of America C-4
Summary Log

Commence logging at 411.75 m

411.75-412.75 m:	CAP ROCK. Angular fragments of red-brown claystone in a red-brown or green clay/mud matrix.
412.75-414.40 m:	MIDDLE HALITE. Red-brown and grey-green argillaceous halite.
414.40-510.27 m:	BASAL HALITE. Coarse, clean, translucent to transparent halite. Weak subhorizontal schistosity.
510.27-511.48 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite..
511.48-511.76 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
511.76-511.99 m:	ORE ZONE. Sylvinite, schistosity dips 45°.
511.99-512.68 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
512.68-512.91 m:	ORE ZONE. Sylvinite.
512.91-513.98 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
513.98-514.16 m:	ORE ZONE. Sylvinite.
514.16-514.60 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
514.60-515.11 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.
515.11-515.36 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
515.36-515.77 m:	ORE ZONE. Sylvinite.
515.77-516.33 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
516.33-516.62 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.
516.62-609.09 m:	BASAL HALITE. Clean, coarse, transparent to translucent halite. Moderate subhorizontal schistosity.

TOTAL DEPTH

Potash Company of America D-2A
Summary Log

Commence logging at 328.64 m

328.64-331.24 m: PENOBSQUIS SALT. Grey to pale orange, coarse halite with anhydrite stringers.

331.24-331.53 m: Red-brown mudstone.

331.53-340.11 m: PENOBSQUIS SALT. Red-brown argillaceous halite with bands of clean halite in central part of unit. Minor anhydrite and blebs of grey-green clay. Lower contact is sharp.

340.11-351.97 m: CAP ROCK. Breccia consisting of angular fragments of anhydrite and red-brown sedimentary rock up to 5 or 6 cm across in a matrix of red-brown mud. Contains some fragments of halite up to 50 cm across.

351.97-354.97 m: HALITE. Contains bands of dark grey argillaceous halite. Grades downward into clean halite.

354.97-360.26 m: CAP ROCK. Breccia as described for 340.11-351.97 m, interbedded with dark grey halite containing interstitial red mud near top. Becomes more matrix-supported downward, and appears sheared toward base, with the shear fabric dipping 20°.

360.26-362.90 m: UPPER ANHYDRITE. Anhydrite with subhorizontal mm-scale mud laminae. Lower contact sharp.

362.90-542.27 m: BASAL HALITE. Core missing, but previous logs describe this interval as basal halite.

542.27-544.96 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Strong schistosity dips 45°.

544.96-550.29 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Strong schistosity dips 45°-50°.

550.29-551.73 m: ORE ZONE [low grade]. Orange clean halite with sylvite as scattered crystals and thin bands. Trace blue halite. Schistosity dips 45°, parallel to banding.

551.73-557.86 m: ORE ZONE. Approximately 10% sylvite with pale orange to light grey halite and minor blue halite. Schistosity dips 45°.

557.86-561.89 m: ORE ZONE [low grade]. As described for 550.29-551.73 m. Weak schistosity dipping 45°.

561.89-564.36 m: ORE ZONE. Sylvinite as described for 551.73-557.86 m.

564.36-564.86 m: ORE ZONE [low grade]. As described for 550.29-551.73 m. Schistosity 45°-50°.

564.86-566.01 m: ORE ZONE. Sylvinite containing 25-30% sylvite, with light grey halite, minor blue halite and disseminated grey-green clay. Strong schistosity dips 50°.

566.01-567.99 m: ORE ZONE [carnallite]. Green-yellow carnallite with light grey halite.

567.99-573.63 m: ORE ZONE. Sylvinite as described for 564.86-566.01 m.

573.63-581.23 m: ORE ZONE [low grade]. Sylvinite interbedded with clean halite with scattered sylvite crystals.

581.23-613.35 m: UPPER HALITE [banded subunit]. Pale orange clean halite interbanded with red-purple argillaceous halite and bands and stringers of anhydrite. Some bands of argillaceous halite contain minor sylvite. Banding and schistosity are parallel, and dip 40°-55°. The schistosity is stronger in bands containing sylvite.

613.35-614.36 m: ORE ZONE [low grade]. Coarse, pale orange halite containing three bands of sylvinite approximately 10 cm thick.

614.36-616.76 m: ORE ZONE. 25-30% sylvite with grey-brown medium grained halite, minor blue halite and a little grey-green clay. Schistosity dips 55°.

616.76-616.99 m: ORE ZONE [low grade]. Translucent to pale pink, coarse to very coarse crystalline halite with scattered crystals of sylvite, trace blue halite and rare crystals of carnallite.

616.99-617.68 m: ORE ZONE. Approximately 25-30% sylvite. Clay content decreases downward. Rare crystals of carnallite near top of unit.

617.68-619.32 m: ORE ZONE. Very coarse, transparent, red-rimmed sylvite with minor carnallite.

619.32-620.47 m: ORE ZONE. Medium-grained sylvinite, 25-30% sylvite. Schistosity dips 40°.

620.47-622.19 m: ORE ZONE. Sylvinite interbedded with 10 cm bands of argillaceous halite with minor carnallite. Carnallite-sylvite aggregates appearing toward base.

622.19-624.29 m: ORE ZONE [carnallite]. As described for 566.01-567.99 m.
624.29-626.06 m: ORE ZONE. Sylvinite with grey-brown halite, minor blue halite and disseminated grey-green clay. Schistosity dips 45°-50°.

626.06-629.51 m: MIDDLE HALITE [red-brown subunit]. Coarse to very coarse with scattered crystals of sylvite in the top 50 cm. Anhydrite stringers parallel to strong schistosity, dipping 60°.

629.51-630.05 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Anhydrite stringers parallel to strong schistosity, dipping 60°.

630.05-669.06 m: BASAL HALITE. Coarse, clean halite, pale orange over top 5 m or so, becoming clear to light grey downward. Anhydritic at base. Schistosity 50° near top, gradually steepening to subvertical by around 650 m.

669.06-669.41 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite, schistosity 80°.

669.41-669.64 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, schistosity 80°.

669.64-679.65 m: ORE ZONE. Approximately 5% sylvite with grey to pale orange halite, blue halite and disseminated grey-green clay. Schistosity 80°-90°.

679.65-720.28 m: UPPER HALITE [banded subunit]. Grey to pale orange halite with minor sylvite, interbedded with red-purple argillaceous halite with borate mineralization and minor sylvite. Banding and schistosity are parallel, dipping 80°.

720.28-722.20 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite, with anhydrite bands parallel to schistosity, dipping 50°. Lower contact gradational over 20 cm.

722.20-736.18 m: BASAL HALITE. Translucent to light grey, coarse halite with anhydrite bands and stringers dying out over the last 10 m or so. Schistosity 45°-60° throughout, and parallel to anhydrite bands.

TOTAL DEPTH

Potash Company of America D-3
Summary Log

Commence logging at 294.02 m

294.02-346.18 m: MABOU GROUP.

346.18-349.05 m: CAP ROCK. Breccia containing subrounded fragments of siltstone and fine sandstone up to several cm across. Matrix of red and green clay and mud. Some clasts are fractured, and healed with gypsum or halite veins. Matrix supported.

349.05-353.16 m: CAP ROCK. Deformed breccia. Flattened clasts of fine grained anhydrite define a strong foliation, dipping 50°-60°.

353.16-360.30 m: CAP ROCK. Breccia as described for 346.18-349.05.

360.30-364.51 m: PENOBSQUIS SALT. Medium-grained, clear to dark grey, argillaceous halite. Bedding and schistosity are parallel, dipping 10°.

346.51-369.13 m: CAP ROCK. Angular fragments of halite up to several cm across, with anhydrite fragments in a matrix of red-brown clay. Sharp lower contact.

369.13-373.04 m: UPPER ANHYDRITE. Brecciated anhydrite. Sharp lower contact.

373.04-386.66 m: BASAL HALITE. Clear to translucent coarse crystalline halite. Contains bands of anhydrite and clay parallel to the schistosity, 20°-30°.

386.66-391.21 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Moderate schistosity dipping 20°-30°.

391.21-392.61 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite with minor sylvite. Moderately schistose, schistosity dipping 30°.

392.61-393.02 m: ORE ZONE. Fine to medium grained sylvinite. Strongly schistose and lineated, schistosity dipping 30°. Lower contact is sharp, and parallel to schistosity.

393.02-421.61 m: UPPER HALITE [banded subunit]. Pale orange clean halite interbedded with purple-red argillaceous halite and low-grade sylvinite. Contains bands and blebs of anhydrite. Strong schistosity dipping 30°.

421.61-423.53 m: ORE ZONE. Schistose sylvinite with disseminated grey clay and minor blue halite.

423.53-427.38 m: UPPER HALITE [banded subunit]. Clear, translucent and pale orange coarse, clean halite with 10 cm bands of red-purple argillaceous halite and low-grade sylvinite. Contains anhydrite bands and stringers. Schistosity dips 30°.

427.38-431.98 m: ORE ZONE. Sylvinite with disseminated grey clay and trace blue halite. Strong schistosity dipping 30°.

431.98-435.98 m:	MIDDLE HALITE. Red-brown to greenish argillaceous halite. Strong schistosity dipping 30°.
435.98-437.68 m:	ORE ZONE. As described for 427.38-431.98 m.
437.68-451.00 m:	UPPER HALITE [banded subunit]. Interbedded pale orange, clean, coarse halite and red-purple argillaceous halite. Anhydrite stringers dip 20°, parallel to schistosity. Three 10 cm thick bands of sylvinite near base. Lower contact sharp.
451.00-465.78 m:	ORE ZONE. As described for 427.38-431.98 m. Strong schistosity dipping 20°-35°.
465.78-474.33 m:	UPPER HALITE [banded subunit]. Interbedded clear to pale pink clean halite, red-purple argillaceous halite, and sylvinite. Banding dips 45°, parallel to schistosity.
474.33-476.02 m:	ORE ZONE. 10-20% sylvite, with grey fine-grained halite, disseminated grey clay and trace blue halite. Strong schistosity dipping 35°.
476.02-478.59 m:	MIDDLE HALITE. Red-brown and grey-green argillaceous halite. Strong schistosity dipping 35°.
478.59-479.42 m:	ORE ZONE. Low-grade sylvinite, with grey schistose halite and a little disseminated grey clay. Schistosity dips 35°.
479.42-488.90 m:	MIDDLE HALITE. Grey-green to red-brown argillaceous halite. Contains some blebs of anhydrite. Moderate schistosity dipping 45°-50°.
488.90-492.60 m:	BASAL HALITE. Clear to translucent, clean, coarse halite. Contains angular anhydrite fragments and spheroidal aggregates up to 6 cm across. Schistosity dips 45°-50°.
492.60-499.52 m:	MIDDLE HALITE. Grey-green to red-brown argillaceous halite. Strong schistosity dipping 30°, shallowing to 20° at base.
499.52-704.32 m:	BASAL HALITE. Clear to light grey, coarse, clean halite. Generally anhydritic, especially near to upper and lower contacts. Schistosity is variable, becoming subvertical over last 80 m.
704.32-710.86 m:	MIDDLE HALITE [grey-green subunit]. Grey-green, coarse, argillaceous halite with traces of sylvinite. One 5 cm thick band of sylvinite near base. Schistosity remains subvertical.
710.86-712.44 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, schistosity subvertical.
712.44-713.53 m:	ORE ZONE. 25-30% sylvite, with grey halite, large amounts of disseminated and blebby grey clay, and relatively high concentrations of blue halite. Strong schistosity dips 70°.
713.53-719.35 m:	UPPER HALITE [banded subunit]. Bands of pale orange clean halite, red-purple argillaceous halite, and sylvinite. Contorted thin bands and stringers of anhydrite. Banding is parallel to schistosity, which dips 70° near the top and 40° at base.

719.35-721.69 m: ORE ZONE. Sylvinite containing large blebs of dark red-brown clay and trace blue halite. Schistosity dips 30°.

721.69-721.89 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

721.89-722.24 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

722.24-804.09 m: BASAL HALITE. Clear to dark grey, coarse halite with small amounts of anhydrite. Schistosity shallows from 70° at the top to 20° at the base. Bands of low-grade sylvinite at 786.95 m and 789.95 m. Becoming slightly argillaceous and more anhydritic to base.

TOTAL DEPTH

Potash Company of America D-4
Summary Log

Commence logging at 467.56 m

467.56-469.53 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

469.53-484.49 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Strong schistosity dipping 20°.

484.49-495.78 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Schistosity dipping 20°.

495.78-499.67 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Schistosity steepening to 40°.

499.67-640.07 m: BASAL HALITE. Clear, clean, coarse to very coarse, crystalline halite. Contains anhydrite blebs and chunks up to several cm across in top 5 m, with anhydrite blebs and stringers in discrete intervals of dark grey halite below that. Little anhydrite below 600 m or so. Schistosity 40° at around 515 m, weakening downward and steepening to subvertical by 605 m.

640.07-648.92 m: LOST CORE.

648.92-659.82 m: BASAL HALITE. Coarse, translucent to light grey, clean halite. Weak, subvertical schistosity. Lower contact dips 80°.

659.82-660.32 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite, schistosity dipping 80°. Lower contact gradational.

660.32-661.28 m: BASAL HALITE. Clear, clean halite. No schistosity. Lower contact dips 50°.

661.28-662.88 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Schistosity is highly variable. Lower contact dips 50°, parallel to schistosity at that point.

662.88-663.44 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite with scattered crystals of sylvite. Strong schistosity 60°-70° throughout, subparallel to lower contact of unit.

663.44-663.88 m: ORE ZONE. Medium-grained sylvinite, with 25% sylvite, translucent to grey halite, disseminated grey-green clay and minor blue halite. Shows sylvite/halite banding giving gneissose appearance. Banding dips 60°, parallel to lower contact of unit.

663.88-665.94 m: ORE ZONE [lower gradational zone]. Clear to pale orange, coarse, clean halite with <1% sylvite. Schistosity approximately 60° throughout.

665.94-666.81 m: ORE ZONE. Sylvinite as described for 663.44-663.88 m. Schistosity 45°-50° throughout. Grey-green argillaceous halite over the last 30 cm.

666.81-667.50 m:	ORE ZONE [lower gradational zone]. Coarse, translucent to grey halite, with <1% sylvite.
667.50-667.70 m:	ORE ZONE. Sylvinite, as described 663.44-663.88 m. Banding dips 50°, parallel to contacts of unit.
667.70-668.12 m:	ORE ZONE [lower gradational zone]. Coarse, pale orange to translucent halite, with <1% sylvite. Schistosity dips 50°.
668.12-668.74 m:	ORE ZONE. Sylvinite, as described for 663.44-663.88 m. Banding dips 50°.
668.74-668.93 m:	ORE ZONE [lower gradational zone]. As described for 667.70-668.12 m.
668.93-669.10 m:	ORE ZONE. Sylvinite as described for 663.44-663.88 m.
669.10-670.00 m:	ORE ZONE [lower gradational zone]. Halite as described for 667.70-668.12 m, with bands of red-brown argillaceous halite at 669.16-669.23 m, 669.38-669.46 m, and 669.55-669.65 m.
670.00-670.23 m:	ORE ZONE. Sylvinite as described for 663.44-663.88 m. Schistosity dips 50°-60°.
670.23-670.45 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, schistosity 50°.
670.45-671.15 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite, schistosity 50°, parallel to lower contact.
671.15-672.43 m:	BASAL HALITE. Coarse to very coarse, clean, translucent halite. Trace sylvite over last metre or so.
672.43-672.55 m:	MIDDLE HALITE. Grey-green argillaceous halite with trace sylvite. Schistosity dips 50°, parallel to lower contact.
672.55-672.77 m:	ORE ZONE. Sylvinite with 10-15% sylvite, grey halite, disseminated grey-green clay and trace blue halite. Schistosity 30°-40°.
672.77-672.84 m:	MIDDLE HALITE. Grey-green argillaceous halite, schistosity dips 50°.
672.84-673.82 m:	BASAL HALITE. Coarse to very coarse, translucent clean halite with trace sylvite. One 10 cm band of argillaceous halite near top.
673.82-674.26 m:	MIDDLE HALITE? Dark grey, argillaceous halite with trace sylvite.
674.26-674.46 m:	BASAL HALITE. As described for 672.84-673.82 m.
674.46-674.79 m:	MIDDLE HALITE? As described for 673.82-674.26 m.
674.79-675.62 m:	BASAL HALITE. As described for 672.84-673.82 m.
675.62-676.13 m:	MIDDLE HALITE? As described for 673.82-674.26 m.

676.13-686.66 m:	UPPER HALITE? [banded subunit]. Diffuse-edged, broad bands of pale orange to grey, clean coarse halite; and sylvitic argillaceous halite with trace blue halite. Schistosity dips 50°.
686.66-693.04 m:	ORE ZONE? [lower gradational zone]. Clean, translucent to pale orange halite, with trace sylvite throughout and 1-2% sylvite over basal 25 cm. Schistosity 45°-50°.
693.04-694.80 m:	ORE ZONE? 5-10% sylvite in grey, argillaceous, schistose halite with blue halite. Schistosity dips 50°.
694.80-696.90 m:	UPPER HALITE? [banded subunit]. As described for 676.13-686.66 m. Sylvite decreasing in concentration over last metre or so.
696.90-705.92 m:	Coarse, clean halite with <1% sylvite. Schistosity 50° to 60° throughout.
705.92-707.32 m:	Sylvitic and slightly anhydritic grey-brown argillaceous halite, with trace blue halite. Schistosity 50°.
707.32-707.56 m:	Coarse, clean halite with trace sylvite. Weak schistosity dips 50°.
707.56-725.94 m:	BASAL HALITE. Coarse, clean, translucent halite. Strong schistosity dips 50° throughout.
725.94-728.90 m:	MIDDLE HALITE. [grey-green subunit]. Grey halite with disseminated grey-green clay and approximately 2% sylvite. Schistosity dips 50°.
728.90-750.04 m:	BASAL HALITE. Coarse to very coarse, translucent to light grey, clean halite. Anhydrite blebs common in middle part of unit.
750.04-750.19 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.
750.19-750.53 m:	BASAL HALITE. As described for 728.90-750.04 m.
750.53-750.99 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.
750.99-766.12 m:	BASAL HALITE. As described for 728.90-750.04 m. Schistosity dips 30°, parallel to lower contact of unit.
766.12-767.32 m:	Anhydritic and argillaceous grey-green halite.
767.32-767.56 m:	Clean halite, lower contact dips 30°.
767.56-767.90 m:	Anhydritic and argillaceous grey-green halite.
767.90-773.56 m:	Coarse to very coarse, translucent clean halite. Schistosity dips 30°.
773.56-774.23 m:	Angular to blebby chunks of anhydrite and clay up to 2 cm across, grading downward into pure anhydrite.
774.23-779.81 m:	Clean halite, schistosity dips 30°. Scattered crystals of sylvite appearing over the last 1-1.5 m.
779.81-779.95 m:	Sylvitic clean to argillaceous halite, weak schistosity dips 30°.

779.95-780.45 m: Clean, coarse, translucent to light grey halite with <1% scattered sylvite crystals. Weak schistosity dips 20°-30°, lower contact dips 45°.

780.45-780.98 m: Medium-grained sylvinite grading 10% sylvite, with translucent to grey halite, disseminated grey-brown clay, and significant blue halite. Sylvite crystals show subhorizontal lineation.

780.98-782.10 m: Coarse, translucent to grey halite with scattered crystals of sylvite <1%. Lower contact dips 20°-30°.

782.10-782.96 m: Sylvinite as described for 780.45-780.98 m.

782.96-784.74 m: Halite as described for 780.98-782.10 m.

784.74-784.76 m: Band of 5% sylvinite.

748.76-748.90 m: Halite as described for 780.98-782.10 m.

748.90-785.03 m: Sylvinite as described for 780.45-780.98 m.
785.03-785.34 m: Halite as described for 780.98-782.10 m.

785.34-785.40 m: Sylvinite as described for 780.45-780.98 m.

785.40-785.59 m: Halite as described for 780.98-782.10 m.

785.59-785.58 m: Sylvinite as described for 780.45-780.98 m.

785.58-790.13 m: Halite as described for 780.98-782.10 m.

790.13-790.52 m: Sylvinite as described for 780.45-780.98 m.

790.52-791.29 m: Halite as described for 780.98-782.10 m.

791.29-793.92 m: Sylvinite with 15% sylvite, translucent to pale grey, medium-grained halite, disseminated grey-brown clay, and 1-2% blue halite.

793.92-795.73 m: Halite as described for 780.98-782.10 m. Schistosity dips 30°.

795.73-795.91 m: Sylvinite grading 5% sylvite. Strong schistosity dips 30°.

795.91-796.13 m: Halite as described for 780.98-782.10 m.

796.13-796.84 m: Sylvinite grading 5% sylvite. Strong schistosity dips 30°.

796.84-797.70 m: Halite as described for 780.98-782.10 m.

797.70-797.77 m: Sylvinite grading 5% sylvite. Strong schistosity dips 30°.

797.77-797.99 m: Halite as described for 780.98-782.10 m.

797.99-798.07 m: Grey-green argillaceous halite.

798.07-798.15 m: Halite as described for 780.98-782.10 m.

798.15-798.34 m: Grey-green argillaceous halite, strong schistosity dips 20°.

798.34-798.47 m: Halite as described for 780.98-782.10 m, schistosity dips 30°.

798.47-798.82 m: Grey-green argillaceous and anhydritic halite.

798.82-799.00 m: Halite as described for 780.98-782.10 m.

799.00-799.05 m: Grey-green argillaceous halite.

799.05-799.17 m: Halite as described for 780.98-782.10 m.

799.17-799.27 m: Grey-green argillaceous halite.

799.27-799.33 m: Halite as described for 780.98-782.10 m.

799.33-799.39 m: Grey-green argillaceous halite.

799.39-812.11 m: Coarse, clean, translucent to grey halite. Schistosity 10°-20° throughout.

TOTAL DEPTH

Potash Company of America E-4A
Summary Log

Commence logging at 513.47 m

513.47-513.92 m: CAP ROCK. Breccia containing angular to subangular fragments of anhydrite up to 2 cm across in a matrix of clay, mud and fine-grained anhydrite. The lower contact is sharp and subhorizontal.

513.92-514.95 m: CAP ROCK. Brecciated anhydrite, consisting of angular anhydrite fragments healed with halite and gypsum veins. The lower contact is sharp and dips 30°.

514.95-516.74 m: CAP ROCK. Anhydrite breccia with clay matrix, as for 513.47-513.92 m. The lower contact is sharp, and dips 30°.

516.74-519.37 m: CAP ROCK. Massive medium-grained to cryptocrystalline blue-grey anhydrite. The lower contact is sharp, and dips 35°.

519.37-520.79 m: CAP ROCK. Breccia as described for 513.47-513.92 m. The lower contact is sharp, and dips 30°.

520.79-520.87 m: CAP ROCK. Massive anhydrite as for 516.74-519.37 m. The lower contact is sharp, and dips 30°.

520.87-520.97 m: CAP ROCK. Breccia as described for 513.47-513.92 m. The lower contact is sharp, and dips 30°.

520.97-529.16 m: CAP ROCK. Massive, fine- to medium-grained, dark blue-grey, crystalline anhydrite. Contains gypsum veins and is brecciated in places. Also contains discontinuous clay bands up to 2 cm thick, dipping 10°-15°. The lower contact is sharp and dips 25°.

529.16-531.56 m: CAP ROCK. Deformed breccia containing angular anhydrite/ gypsum and red-brown mudstone fragments in a matrix of mud and clay. Anhydrite clasts are flattened into a pronounced s-foliation which dips 50°.

531.56-554.93 m: UPPER HALITE [banded subunit]. Bands of clean translucent to pale orange coarse crystalline halite, interbedded with purple-red argillaceous halite and low-grade sylvinite. Contacts gradational over 10 cm or so. Some anhydrite stringers. Dip 50°.

554.93-598.08 m: ORE ZONE. Irregular aggregates of brick-red sylvite with translucent to grey halite and grey-brown disseminated clay. Trace of blue halite. Dip 50°. A set of halite veins dips 60°. The sylvinite becomes interbedded with clear to pale orange clean halite over the basal 17 m or so.
598.08-599.87 m: ORE ZONE [lower gradational zone]. Approximately 5% sylvite in moderately schistose, coarse, clean halite. Schistosity dips 30°.

599.87-619.33 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Moderately schistose, schistosity dipping 25°. A few anhydrite stringers dipping 25° toward base. Lower contact is gradational.

619.33-651.77 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite Clay content decreases and anhydrite content increases downward. Dip 30°.

651.77-740.38 m: BASAL HALITE. Clear to pale orange halite, grading into translucent to light grey coarse, crystalline halite. Contains anhydrite lumps and bands up to 10 cm thick, of highly variable dip. The halite is slightly schistose, and the schistosity is also of highly variable dip. The halite is very clean between 711.20-737.50 m. Becoming dark grey toward base.

740.38-747.28 m: MIDDLE HALITE [grey-green subunit]. Medium to coarse grained, grey-green argillaceous halite, with scattered blebs of anhydrite up to 1 cm in diameter. Lower contact is gradational.

747.28-755.80 m: MIDDLE HALITE [red-brown subunit]. Medium grained, red-brown argillaceous halite.

755.80-757.80 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

757.80-759.40 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, becoming slightly sylvinitic toward base.

759.40-760.90 m: ORE ZONE. Sylvite up to 10%, with clear halite and minor blue halite. Schistose, schistosity dips 10°.

760.90-779.09 m: UPPER HALITE [banded subunit]. Bands of pale orange clean halite and purple-red argillaceous halite. Bands are approximately 10 cm thick, and have gradational contacts. Some anhydrite bands, trace sylvite. Dip of banding is parallel to dip of schistosity, and varies 60° to subhorizontal.

779.09-780.39 m: ORE ZONE. Low grade sylvinite, 5-15%. Strong schistosity dipping 30°-40°.

780.39-798.32 m: UPPER HALITE [banded subunit]. As described for 760.90-779.09.

798.32-799.82 m: ORE ZONE. Sylvinite, grade ~25%. Well developed gneissosity dipping 60°-80°. Contains trace blue halite and small amounts of disseminated grey clay.

799.82-801.32 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite, with clay bands dipping 40°. Becoming cleaner toward base.

801.32-816.17 m: BASAL HALITE. Clear to pale orange, coarse, crystalline clean halite. Slightly schistose, with schistosity variable throughout. Contains a few anhydrite bands which are parallel to the schistosity.

816.17-818.54 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

818.54-819.89 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite with trace sylvite. Slightly schistose, dipping 20°.

819.89-823.09 m: ORE ZONE. Sylvinite, containing a 40°-50° schistosity.

823.09-846.80 m:	UPPER HALITE [banded subunit]. Clean, translucent to light grey, coarse, crystalline halite interbedded with red-purple argillaceous halite and sylvinite. Dips variable.
846.80-847.60 m:	ORE ZONE. Schistose sylvinite, containing trace blue halite and small amounts of disseminated grey clay.
847.60-860.26 m:	MIDDLE HALITE. Bands of argillaceous and clean halite, with anhydrite stringers which are parallel to the 30° schistosity.
860.26-919.58 m:	BASAL HALITE. Coarse, clear, schistose, crystalline halite. Schistosity is variable. Becoming mylonitic toward base.
TOTAL DEPTH	

Potash Company of America G-3A
Summary Log

Commence logging at 457.50 m

457.50-459.61 m: CAP ROCK. Subangular clasts, up to 4-5 cm across, of red-brown sedimentary rock in a matrix of red or green clay and mud.

459.61-462.41 m: CAP ROCK. Brecciated anhydrite with fractures containing clay or halite. Grades into brecciated gypsiferous anhydrite healed with gypsum veins downward.

462.41-463.01 m: CAP ROCK. Massive anhydrite.

463.01-475.57 m: CAP ROCK. Brecciated gypsiferous anhydrite. Includes 10 cm bands of clay-matrix breccia. Deformed toward base. Dip 25°.

475.57-480.10 m: CAP ROCK. Red-brown clay and mudstone, containing bands of brecciated mudstone. Dip 40°.

480.10-484.16 m: CAP ROCK. Angular fragments of anhydrite approximately 1 cm across in a matrix of red-brown mud and clay. Sheared at base.

484.16-502.46 m: LOST CORE

502.46-508.45 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, some anhydrite.

508.45-581.47 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Becoming less argillaceous and more anhydritic downward.

581.47-593.58 m: TRANSITION ZONE. Translucent to dark grey halite with bands, stringers and blebs of anhydrite. Anhydrite less common downward.

593.58-697.59 m: BASAL HALITE. Coarse, translucent to clear, crystalline halite. Weak schistosity dipping 10°-20°. Becoming anhydritic over last 20 m or so.

697.59-702.64 m: MIDDLE HALITE [grey-green subunit]. Orange to grey halite with disseminated grey-green clay.

702.64-713.70 m: BASAL HALITE. Clear to translucent, coarse, slightly anhydritic halite. Schistosity dips 30°.

713.70-716.27 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Schistosity dips 30°. Lower contact gradational over a few cm.

716.27-717.15 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Lower contact sharp.

717.15-718.70 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

718.70-718.98 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

718.98-721.65 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

721.65-722.00 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

722.00-722.61 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

722.61-724.02 m: BASAL HALITE. Translucent to pale orange halite with blebs and stringers of anhydrite throughout, more common toward top.

724.02-725.32 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

725.32-729.00 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

729.00-747.87 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

747.87-846.30 m: BASAL HALITE. Translucent to pale grey, coarse, crystalline halite. Anhydrite in first 1 m or so; very clean thereafter. Strong schistosity highly variable in orientation. Toward base, very coarse crystalline halite in a matrix of medium- to fine-grained schistose halite.

TOTAL DEPTH

Potash Company of America G-4A
Summary Log

Commence logging at 607.93 m

607.93-630.48 m:	PENOBSQUIS SALT. Orange to grey argillaceous halite. Clay may be disseminated, or as bands and jagged interstitial masses, and is grey-green or brown in colour. Toward base contains anhydrite bands up to 20 cm thick. Bands dip 20°, steepening to 40°-45° toward base. Lower contact is sharp.
630.48-635.58 m:	UPPER ANHYDRITE. Fine-grained, massive, blue-grey anhydrite. Lower contact is sharp but irregular, and approximately horizontal.
635.58-639.53 m:	UPPER HALITE [coarse subunit]. Coarse, crystalline, slightly argillaceous, clear to translucent halite. Contains clay laminae dipping 40°-45°.
639.53-646.69 m:	UPPER HALITE [finely laminated subunit]. Orange and grey banded halite with mm-scale clay laminae throughout. Dips highly variable.
646.69-649.45 m:	UPPER HALITE [sylvinite subunit]. Sylvinite and halite containing fine clay laminae, with sylvinite concentrated in bands 10-20 cm thick. Dips are variable.
649.45-683.94 m:	UPPER HALITE [banded subunit]. Heterogeneous, broad-banded, translucent to deep orange clean halite interbedded with red-purple argillaceous halite. Variable, but generally low angle, schistosity dipping 30° to horizontal. Some anhydrite stringers in lower part. At base, orange clean halite with sylvinite bands at 679.96 m, 683.23 m, and 683.53 m.
683.94-699.33 m:	ORE ZONE.
699.33-707.29 m:	ORE ZONE [lower gradational zone]. Clean orange halite with sylvinite bands and scattered fine crystals of sylvite. Sylvite concentration decreases downward.
707.29-733.48 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Dip approximately 20°.
733.48-771.46 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Strong and highly variable schistosity, 30° to horizontal. Bedding is defined by bands of anhydrite and clay, and dips 40°. Lower contact is gradational over 50 cm or so.
771.46-775.29 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Schistosity approximately horizontal, clay laminae dip 40°-50°.
775.29-776.74 m:	ORE ZONE [lower gradational zone]. Orange clean halite with scattered fine crystals of sylvite. Sylvite concentration increases downward.
776.74-778.02 m:	ORE ZONE. Fine-grained sylvinite containing significant blue halite. Coarser in middle part of unit.

778.02-780.17 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Weak subhorizontal schistosity.
780.17-781.79 m:	ORE ZONE [lower gradational zone]. Low-grade sylvitic halite, as described for 775.29-776.74 m.
781.79-782.39 m:	ORE ZONE. Sylvinite, as described.
782.39-782.69 m:	ORE ZONE [lower gradational zone]. As described for 775.29-776.74 m.
782.69-790.46 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
790.46-792.06 m:	ORE ZONE. Strongly schistose, medium-grained sylvinite. Grades into orange clean halite with sylvinite bands toward base. Bedding and schistosity are parallel and dip 25°.
792.06-813.52 m:	UPPER HALITE [banded subunit]. Bands of translucent clean halite, pale orange clean halite, and red-purple argillaceous halite. Argillaceous bands may contain minor sylvite. Strongly schistose. Schistosity is parallel to bedding and dips 20° to horizontal.
813.52-824.02 m:	ORE ZONE. Medium-grained sylvinite with disseminated grey-green clay and trace blue halite. Several fracture surfaces dipping 60°-70°.
824.02-826.33 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Schistosity dips 30°. Lower contact gradational over 50 cm or so.
826.33-827.45 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Schistosity dips 30°. Lower contact gradational over 2 cm, subparallel to schistosity.
827.45-829.62 m:	BASAL HALITE. Clear to translucent clean halite, with fine-grained anhydrite aggregates up to 10 cm across near top. Schistosity dips 45°.
829.62-831.77 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.
831.77-835.00 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
835.00-840.22 m:	ORE ZONE. Medium- to coarse-grained sylvinite, with disseminated grey clay and trace blue halite.
840.22-857.88 m:	UPPER HALITE [banded subunit]. Bands of translucent to pale orange clean halite, and red-purple argillaceous halite. Contains a few anhydrite stringers. Dip is variable, but parallel to schistosity. Schistosity disappears toward base.
857.88-859.21 m:	ORE ZONE. As described for 835.00-840.22 m.
859.21-860.04 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite with scattered fine sylvite crystals.
860.04-860.46 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

860.46-900.79 m:	BASAL HALITE. Translucent to light grey clean halite. A few anhydrite stringers in top 10 cm. Coarsening downward, coarse to very coarse clean halite in a fine-grained halite matrix toward base.

TOTAL DEPTH

Potash Company of America H-4A
Summary Log

Commence logging at 523.38 m

523.38-526.66 m: CAP ROCK. Angular fragments up to several cm across of siltstone and gypsum/anhydrite in a grey-green or red muddy matrix. Clast supported. Gypsum veins dipping 70°.

526.66-526.92 m: CAP ROCK. Finely crystalline, blue-grey brecciated anhydrite. Fractures are healed with gypsum and contain angular clasts of red siltstone up to a few mm across.

526.92-527.11 m: CAP ROCK. As described for 523.38-526.66 m.

527.11-528.46 m: CAP ROCK. As described for 526.66-526.92 m.

528.46-528.84 m: CAP ROCK. As described for 523.38-526.66 m.

528.84-529.38 m: CAP ROCK. As described for 526.66-526.92 m.

529.38-531.00 m: CAP ROCK. As described for 523.38-526.66 m.

531.00-532.36 m: CAP ROCK. As described for 526.66-526.92 m.

532.36-534.05 m: CAP ROCK. Brecciated blue-grey, finely crystalline, anhydrite with bands of breccia as described for 523.38-526.66 m, many of which are sheared. Lower contact is gradational, with large fragments of anhydrite in a muddy matrix giving way downward to breccia as described for 523.38-526.66 m.

534.05-539.05 m: CAP ROCK. As described for 523.38-526.66, rather coarse near base with clasts up to 4-5 cm across.

539.05-540.53 m: CAP ROCK. Fragments of brecciated anhydrite healed with gypsum veins, in a muddy matrix. Sheared, lower contact sharp.

540.53-550.56 m: UPPER HALITE [banded subunit]. Broad bands of pale orange, clean halite with anhydrite bands up to 5 cm thick, interbedded with red-purple argillaceous halite with bands of red-brown clay and mm-thick anhydrite stringers. Dip around 30° throughout.

550.56-551.06 m: ORE ZONE. Approximately 20% sylvite with orange and grey halite, and small amounts of disseminated grey-green clay. Moderate schistosity dips 60°, parallel to upper and lower contacts of unit.

551.06-551.72 m: ORE ZONE [lower gradational zone]. Coarse, clean, pale orange halite.

551.72-552.20 m: ORE ZONE. As described for 550.56-551.06 m.

552.20-553.55 m: ORE ZONE [lower gradational zone]. As described for 551.06-551.72 m.

553.55-554.19 m: ORE ZONE. As described for 550.56-551.06 m.

554.19-554.90 m: ORE ZONE [lower gradational zone]. As described for 551.06-551.72 m.

554.90-571.24 m: ORE ZONE. As described for 550.56-551.06 m, dip 60°.

571.24-593.22 m: ORE ZONE [lower gradational zone]. As described for 551.06-551.72 m.

593.22-616.12 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

616.12-621.90 m: MIDDLE HALITE [transition zone]. Transition from red-brown to grey-green argillaceous halite, with bands of clean halite approximately 10 cm thick.

621.90-660.19 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite, with bands of pale orange clean halite increasing in frequency downward.

660.19-847.80 m: BASAL HALITE. Coarse, clean, translucent to light grey, crystalline halite.

TOTAL DEPTH

Potash Company of America H-5
Summary Log

Commence logging at 656.97 m

656.97-665.33 m:	PENOBSQUIS SALT. Leached core, argillaceous halite.
665.33-697.73 m:	PENOBSQUIS SALT. Very coarse argillaceous halite with disseminated grey clay and mm-scale laminae of grey clay. Increasing amounts of red-brown clay appearing downward, first as interstitial clay and then as mm-cm scale bands. Becoming anhydritic toward base. Dip of clay bands around 10°.
697.73-702.75 m:	PENOBSQUIS SALT. Coarse to very coarse, grey to pale orange crystalline halite with anhydrite bands up to 40 cm+ thick. Anhydrite bands associated with laminated and interstitial clay. Dip of anhydrite bands in general <20°.
702.75-706.89 m:	UPPER ANHYDRITE. Fine-grained, blue-grey, massive anhydrite, with significant clay content as bands and irregular blebs near to upper and lower contacts. Dip around 10°.
706.89-708.25 m:	UPPER HALITE [coarse subunit]. Coarse, dark grey, argillaceous halite. Clay is disseminated, and as irregular blebs and mm-scale discontinuous laminae.
708.25-715.04 m:	UPPER HALITE [laminated subunit]. Grey to orange halite with mm-scale laminae of grey clay at intervals of 1 cm to a few cm. Dip around 10°.
715.04-719.92 m:	UPPER HALITE [laminated subunit with borates]. As described for 708.25-715.04 m, but with spheroidal aggregates of platy orange borate crystals and powdery white borate crystals. Also a little sylvite in rare discrete bands up to a few cm thick.
719.92-722.01 m:	UPPER HALITE [sylvinite subunit]. Orange clean halite interbedded with grey argillaceous halite, and bands of sylvinite up to 10 cm thick containing up to 10% scattered crystals of sylvite. Scattered crystals of pale orange platy borates throughout.
722.01-731.27 m:	UPPER HALITE [banded subunit]. Broad bands of clean, pale orange, coarse halite and red or grey argillaceous halite. Highly heterogeneous.
731.27-733.75 m:	UPPER HALITE [banded subunit]. Coarse, clean, translucent to pale grey halite with bands containing approximately 10% sylvite, sometimes associated with red-brown disseminated clay.
733.75-735.82 m:	UPPER HALITE [banded subunit]. Coarse, clean, light grey to pale orange halite.
735.82-746.17 m:	UPPER HALITE [banded subunit]. Coarse, pale orange halite with anhydrite bands, generally on the order of a few mm thick, but up to 1.5 cm. Dip around 10°.

746.17-752.65 m: ORE ZONE. Sylvinite with approximately 30% sylvite, grey halite, grey clay (both disseminated and as ~1 cm blebs), minor red-brown clay, and trace blue halite.

752.65-784.49 m: MIDDLE HALITE [red-brown subunit]. Very coarse, red-brown argillaceous halite interbanded with orange clean halite. Argillaceous bands becoming dirtier, and clean bands less frequent, toward base. Grey clay becoming common as blebs and cm-scale bands from around 774 m, but halite retains a red-brown colour from finely disseminated clay until base. Dip 10°-20° throughout.

784.49-799.59 m: MIDDLE HALITE [grey-green subunit]. Very coarse, pale orange halite with grey-green clay (disseminated and as blebs and cm-scale bands).

799.59-809.94 m: TRANSITION ZONE. Clean, translucent to pale grey or orange, coarse halite with anhydrite and clay bands on the order of 1-2 cm thick. Bands are generally subhorizontal, but some are irregular and contorted. Clay bands less common toward base.

809.94-813.09 m: BASAL HALITE. Coarse, clean, translucent to pale orange halite with occasional anhydrite bands up to 2 cm thick. Dip 10° or so.

813.09-817.97 m: BASAL HALITE. Clean, translucent to light grey, coarse halite with significant anhydrite in bands generally a few cm thick, but up to 25 cm. Halite has a red tint at 816.13-816.53 m and 813.83-814.03 m. Dip subhorizontal to 10°.

817.97-858.43 m: BASAL HALITE. Coarse, clean, translucent halite with a little anhydrite-very clean in central part of unit. Anhydrite bands are subhorizontal, but are slightly irregular and contorted in many cases. Weakly developed schistosity dips subhorizontal to 15°.

858.43-882.88 m: BASAL HALITE. Coarse, clean, translucent halite with contorted anhydrite stringers throughout. Weak subhorizontal schistosity, becoming stronger toward base.

TOTAL DEPTH

Potash Company of America I-4
Summary Log

Commence logging at 493.80 m

493.80-498.33 m: CAP ROCK. Angular fragments of red-brown sedimentary rock in a matrix of red or green mud and clay. Deformed toward base, with gypsum- and halite-infilled fractures.

498.33-506.95 m: CAP ROCK. Gypsiferous anhydrite with fractures infilled with gypsum and halite. Some brownish clay bands toward base. Lower contact sharp.

506.95-509.49 m: CAP ROCK. Rounded to subrounded fragments of red or green claystone and mudstone up to 5-6 cm across. Matrix of red-brown mud and clay.

509.49-510.26 m: CAP ROCK. Brecciated anhydrite with mud-filled fractures and some halite-filled fractures. Lower contact fairly sharp.

510.26-511.06 m: CAP ROCK. As described for 506.95-509.49 m.

511.06-511.96 m: CAP ROCK. As described for 509.49-510.26 m.

511.96-521.00 m: CAP ROCK. Massive anhydrite with bands of anhydrite breccia dipping 60°-70°. Breccia bands have gradational contacts into unfractured anhydrite. Toward base, the breccia bands become thinner, sharper, and dip 10°-20°. Lower contact is sharp, dipping 10°-20°.

521.00-521.34 m: CAP ROCK. Breccia as described for 506.95-509.49 m, but becoming finer grained toward base, and containing clasts of halite. Lower contact sharp, dip approximately 20°.

521.34-525.55 m: UPPER HALITE [finely laminated subunit]. Pale orange to light grey halite interbedded with red-purple argillaceous halite and mm-scale laminae of grey-green clay. Dip 45°. Lower contact gradational.

525.55-530.07 m: UPPER HALITE [sylvinite subunit]. As described for 521.34-525.55 m, but with sylvite up to a few % in the argillaceous bands, and as bands of scattered crystals in orange clean halite. Dip 45°.

530.07-539.83 m: UPPER HALITE [banded subunit]. Red-purple argillaceous halite with 2 cm aggregates of platy orange borate crystals, interbedded with pale orange to dark grey clean halite. Dip 45°.

539.83-561.78 m: ORE ZONE. Core boxes missing.

561.78-569.47 m: ORE ZONE [lower gradational zone]. Low-grade sylvitic halite.

569.47-570.87 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite. Dip 40°.

570.87-584.38 m: ORE ZONE [lower gradational zone]. As described for 561.78-569.47 m.

584.38-611.64 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

611.64-651.44 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

651.44-702.59 m: BASAL HALITE. Coarse, clean, crystalline halite. Weak schistosity 45° near top, subhorizontal near base.

TOTAL DEPTH

Potash Company of America M-4A
Summary Log

Commence logging at 500.81 m

500.81-524.60 m:	UPPER HALITE [laminated subunit]. 1-2 cm thick bands of orange-brown, grey and clear halite; and sylvinite associated with white aggregates of borate minerals up to 1 cm in diameter. Numerous mm-scale laminae of grey-green clay throughout. Laminae become less distinct toward base; lower contact gradational. Dip 70° throughout.
524.60-544.43 m:	UPPER HALITE [laminated with borates]. As described for 500.81-524.60 m, but bands are broader, 5-6cm, and boundaries more diffuse. Significant borate mineralization. Dip 70° at top, 50° at base.
544.43-589.87 m:	UPPER HALITE [banded subunit]. Interbedded clear and orange coarse halite with some mm-scale laminae of grey-green clay. Variable concentrations of borate aggregates and scattered sylvite crystals. Low-grade sylvinite (<10%) bands up to 30 cm thick toward base. Dip highly variable throughout.
589.87-615.40 m:	ORE ZONE. Sylvinite, with fine-grained sylvite up to 30%, with clear to grey, medium-grained halite, minor blue halite, and a little disseminated grey-green clay.
615.40-635.32 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
635.32-664.90 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Anhydritic toward base.
664.90-713.70 m:	BASAL HALITE. Coarse to very coarse, clean, transparent to light grey halite, with bands and blebs of anhydrite. Banding and schistosity subhorizontal.
713.70-720.41 m:	MIDDLE HALITE [grey-green subunit]. Orange halite with disseminated grey clay and bands of grey clay, a little anhydrite. Clay bands dip 45°, parallel to schistosity.
720.41-723.46 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, with anhydrite bands and schistosity both dipping 30°. Lower contact gradational.
723.46-727.43 m:	ORE ZONE. Sylvinite grading approximately 20% sylvite, with orange-red to grey halite and disseminated greenish clay. Pronounced schistosity in sylvite crystals dips 60°.
727.43-737.67 m:	UPPER HALITE [banded subunit]. As described for 544.43-589.87 m.
737.67-742.37 m:	UPPER HALITE [laminated with borates]. As described for 524.60-544.43 m.
742.37-748.78 m:	UPPER HALITE [laminated subunit]. As described for 500.81-524.60 m.
748.78-758.54 m:	UPPER ANHYDRITE. Dark blue to grey, fine-grained to cryptocrystalline, massive anhydrite.

758.54-821.37 m: PENOBSQUIS SALT. Coarse to very coarse, pale orange to dark grey, argillaceous halite.

821.37-836.00 m: UPPER ANHYDRITE. As described for 748.78-758.54 m.

836.00-848.51 m: UPPER HALITE [laminated subunit]. As described for 500.81-524.60 m.

848.51-855.53 m: UPPER HALITE [laminated with borates]. As described for 524.60-544.43 m.

855.53-862.85 m: UPPER HALITE [banded subunit]. As described for 544.43-589.87 m.

862.85-863.85 m: ORE ZONE. As described for 723.46-727.43 m.

863.85-864.37 m: MIDDLE HALITE. Red-brown and grey-green argillaceous halite.

864.37-878.40 m: BASAL HALITE. Coarse, clean, translucent to light grey halite. Schistosity dips 45°.

TOTAL DEPTH

Potash Company of America N-2
Summary Log

Commence logging at 561.20 m

561.20-591.16 m: UPPER HALITE [banded subunit]. Banded grey-green argillaceous halite; orange-red argillaceous halite; pale orange, coarse, clean halite; red-brown slightly sylvitic argillaceous halite; and strongly schistose dark grey to orange, argillaceous halite. Schistosity 15°-20°, parallel to banding.

591.16-591.75 m: ORE ZONE. Very coarse, translucent to pale orange, clean halite with deep red and transparent sylvite crystals. Strongly schistose argillaceous halite over the last 14 cm.

591.75-594.36 m: ORE ZONE [carnallite]. Powder-yellow carnallite with coarse, grey halite.

594.36-597.24 m: ORE ZONE. Translucent to grey coarse halite with approximately 5% fine-grained sylvite, 2-3% yellow carnallite and trace fine-grained blue halite. Contains interstitial orange-brown clay, increasing in concentration downward.

597.25-599.62 m: ORE ZONE. Light grey, coarse, argillaceous halite with scattered crystals of sylvite and trace carnallite.

599.62-601.06 m: ORE ZONE. As described for 594.36-597.24 m.

601.06-606.55 m: ORE ZONE. Argillaceous halite with scattered crystals of sylvite, trace carnallite and blue halite, with bands of pale orange, coarse, clean halite.

606.55-629.17 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, schistosity 35°-40°.

629.17-668.98 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite, becoming anhydritic over last 6 m or so. Schistosity slightly variable, 45°-60°.

668.98-695.29 m: BASAL HALITE. Coarse, clean, translucent to light grey halite, anhydritic over top 8 m or so. Toward base, very coarse halite in a matrix of fine- to medium-grained schistose halite.

TOTAL DEPTH

Potash Company of America N-3
Summary Log

Commence logging at 350.75 m

350.75-364.33 m: INTERFOLDED UNIT: MIDDLE HALITE [red-brown subunit]/ORE ZONE [lower gradational zone]. Coarse, red-brown, argillaceous halite with blebs of red-brown clay and minor grey-green clay, interbedded with 10-20 cm thick bands of deep orange, clean halite. Contacts are gradational over 2 cm or so. Clean halite bands becoming more important toward base, and scattered sylvite aggregates increasing in concentration.

364.33-364.63 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite with trace sylvite.

364.63-366.43 m: ORE ZONE [lower gradational zone]. Medium to coarse, pale orange, translucent and light grey halite with bands and scattered crystals of sylvite, often associated with grey-green clay. Sporadically developed schistosity is highly variable, suggesting unit may be internally folded.

366.43-366.93 m: MIDDLE HALITE [red-brown subunit]. As described for 364.33-364.63 m.

366.93-367.30 m: ORE ZONE [lower gradational zone]. As described for 364.63-366.43 m.

367.30-368.43 m: MIDDLE HALITE [red-brown subunit]. As described for 364.33-364.63 m.

368.43-368.85 m: ORE ZONE [lower gradational zone]. As described for 364.63-366.43 m.

368.85-371.27 m: MIDDLE HALITE [red-brown subunit]. As described for 364.33-364.63 m. Schistosity is of variable dip.

371.27-375.63 m: ORE ZONE [lower gradational zone]. As described for 364.63-366.43 m. Schistosity is of variable dip.

375.63-377.82 m: INTERFOLDED UNIT: MIDDLE HALITE [red-brown subunit]/ORE ZONE [lower gradational zone]. As described for 350.75-364.33 m.

377.82-441.30 m: MIDDLE HALITE [red-brown subunit]. Contains bands of deep orange, clean halite until ~420 m. Becoming anhydritic over final 4 m or so. Lower contact gradational, placed at point where red-brown clay disappears. Dips:

30°-40°	382 m
35°-40°	400 m
20°	420 m
20°-30°	425 m

441.30-487.86 m: MIDDLE HALITE [grey-green subunit]. Coarse, grey-green, argillaceous halite. Contains bands of clay and anhydrite in lower half of unit. Dips in lower half variable: subhorizontal to 40°.

487.86-496.17 m: MIDDLE HALITE [transition zone]. Bands of pale orange to orange, clean halite with occasional blebs of anhydrite. Dip 20°-30°.

496.17-545.61 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite containing bands of pale orange, clean halite up to 30 cm thick, but usually 10 cm or less in thickness.
545.61-554.30 m:	MIDDLE HALITE [transition zone]. As described for 487.86-496.17 m.
554.30-606.97 m:	MIDDLE HALITE [grey-green subunit]. Grey-green, argillaceous, slightly anhydritic halite. Contains 20-30 cm thick bands of clean halite throughout. Dip highly variable.
606.97-609.42 m:	MIDDLE/BASAL HALITE [transition zone]. Translucent to light grey, coarse halite interbedded with dark grey argillaceous and anhydritic halite. Bands are up to 20 cm thick. Dips highly variable.
609.42-632.35 m:	BASAL HALITE. Translucent to light grey, coarse, clean halite with dark grey anhydritic halite. Anhydrite forms large, irregular clots and patches. Anhydrite decreasing in concentration downward, with just rare contorted bands at base of hole. Schistosity is weak and subvertical.
TOTAL DEPTH	

Potash Company of America P-1
Summary Log

Commence logging at 588.65 m

588.65-590.47 m:	MABOU GROUP. Red-brown mudstone and claystone with anhydrite bands up to 1 cm thick. Dip 40°.
590.47-600.85 m:	UPPER ANHYDRITE. Blue-grey, finely crystalline, massive anhydrite. Locally contains small amounts of brownish clay.
600.85-604.21 m:	UPPER HALITE [coarse subunit]. Coarse, grey to pale orange-red halite with grey-green interstitial clay.
604.21-615.13 m:	UPPER HALITE [laminated subunit]. Orange, clean halite and red-purple argillaceous halite with mm-scale laminae of grey-green clay throughout. Dip slightly variable, but always <30°.
615.13-615.28 m:	UPPER HALITE. Very coarse, clean halite with very coarse, red-rimmed, transparent sylvite crystals in the lower few cm.
615.28-617.21 m:	UPPER HALITE [laminated subunit]. As described for 604.21-615.13 m.
617.21-631.27 m:	UPPER HALITE [banded subunit]. Bands <10 cm thick of pale orange, coarse, clean halite and thicker bands of brown to red-brown argillaceous halite. Contains disseminated grey-green clay throughout. Contains sylvite over top metre or so. Schistosity dips 35° throughout, parallel to banding.
631.27-633.63 m:	UPPER HALITE [laminated subunit]. Low-grade sylvinite and argillaceous red-brown halite with mm-scale laminae of grey-green clay throughout. Dip 35°, parallel to sporadically developed schistosity.
633.63-648.38 m:	UPPER HALITE [banded subunit]. Grey-brown argillaceous halite, becoming red-purple toward base. A little anhydrite at base.
648.38-663.06 m:	UPPER HALITE [banded subunit]. Coarse, clean, pale orange halite with bands of argillaceous halite which become increasingly anhydritic downward, especially over the last 5 m. Schistosity developed over the last 5 m or so, dipping 35°, parallel to anhydrite bands.
63.06-664.00 m:	UPPER HALITE [banded subunit]. Low grade sylvinite, grading 10-15% sylvite, with grey to orange halite and significant amounts of disseminated grey-green clay. A few bleb-like borate aggregates around 2 mm across over the last 0.5 m or so.
664.00-664.76 m:	UPPER HALITE [banded subunit]. Medium grained, pale orange clean halite, with scattered sylvite crystals <1%.
664.76-666.31 m:	UPPER HALITE [banded subunit]. Pale orange carnallite with sylvite and halite. Core in poor shape.
666.31-667.52 m:	UPPER HALITE [banded subunit]. As described for 664.76-666.31 m.
667.52-667.61 m:	UPPER HALITE [banded subunit]. Carnallite-halite zone.

667.61-668.17 m: UPPER HALITE [banded subunit]. As described for 664.00-666.76 m, with coarse to very coarse, transparent halite and transparent, orange-rimmed sylvite at base.

668.17-670.16 m: UPPER HALITE [banded subunit]. Sylvinite as described for 663.06-664.00 m.

670.16-671.41 m: UPPER HALITE [banded subunit]. Banded argillaceous red-brown halite and coarse, clean halite.

671.41-672.01 m: UPPER HALITE [banded subunit]. Sylvinite as described for 663.06-664.00 m.

672.01-676.77 m: UPPER HALITE [banded subunit]. Banded pale orange, clean halite and dark brown argillaceous halite. Scattered crystals of sylvite increasing in concentration toward base.

676.77-677.40 m: UPPER HALITE [banded subunit]. Halite with scattered crystals of sylvite and clay laminae. Dip 30°.

677.40-679.86 m: UPPER HALITE [banded subunit]. Yellow-green carnallite zone.

679.86-685.59 m: ORE ZONE. Sylvinite grading 30-40% sylvite, gradually decreasing to a few % at base of unit. Subhorizontal schistosity.

685.59-688.05 m: UPPER HALITE [banded subunit]. Banded red-brown argillaceous halite and clean, coarse, translucent halite.

688.05-689.57 m: ORE ZONE. Low sylvite grade in red-brown argillaceous halite.

689.57-700.01 m: ORE ZONE. Sylvinite grading 30-40% sylvite, with 10% blue halite, grey halite and a little disseminated clay. Some bands of coarse, clean, transparent halite <10 cm thick. Dip 15°.

700.01-703.26 m: ORE ZONE [lower gradational zone]. Coarse, clean, pale orange halite with scattered crystals of sylvite 1-2%.

703.26-742.99 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, cleaner than observed elsewhere, with approximately 1% sylvite near top dying out over first 5 m or so.

742.99-751.96 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

751.96-794.14 m: BASAL HALITE. Coarse, transparent to translucent, clean halite. Some large lumps of anhydrite, up to 25 cm across, in top 2.5 m.

TOTAL DEPTH

Potash Company of America P-4
Summary Log

Commence logging at 541.38 m

541.38-554.89 m: UPPER HALITE [coarse subunit]. Coarse to very coarse, banded dark grey argillaceous, slightly anhydritic halite, and clean, translucent, pale orange halite. Dip 70° at 548.80, lower contact 40°.

554.89-564.40 m: UPPER HALITE [laminated subunit]. Banded coarse, clean, deep orange halite and red-purple argillaceous halite, with mm-scale laminae of grey-green clay throughout. Dip 50°-70° throughout.

564.40-596.24 m: UPPER HALITE [laminated subunit with borates]. As described for 554.89-564.40 m, with some sylvinite bands and significant borate mineralization.

594.24-650.08 m: UPPER HALITE [banded subunit]. Bands on the order of 1 m to several metres thick, of red-purple argillaceous halite; clean, coarse, translucent and/or pale orange halite; and clean, translucent halite with a few mm-scale anhydrite laminae. Dip variable, some evidence of folding within unit, including folded clay bands.

650.08-655.90 m: ORE ZONE. Pale orange halite with scattered sylvite crystals and bands of sylvite concentration.

655.90-668.07 m: ORE ZONE. Sylvinite, with blue halite, grey halite and disseminated grey-green clay.

668.07-670.73 m: ORE ZONE. As for 655.90-668.07, but coarser, less blue halite, and containing some very coarse light orange sylvite crystals, with less clay.

670.23-683.20 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

683.20-735.05 m: MIDDLE HALITE [grey-green subunit]. Orange halite with grey-green clay over first 5 m or so, grading into grey-green argillaceous halite. Clay as jagged interstitial masses, disseminated blebs and contorted bands and laminae. Some anhydrite laminae are also present. Becoming cleaner toward base, but lower contact sharp.

735.05-860.01 m: BASAL HALITE. Coarse, clean, translucent to light grey halite.

TOTAL DEPTH

Potash Company of America S-4
Summary Log

Commence logging at 527.65 m

527.65-534.17 m: UPPER HALITE [banded subunit]. Bands of red-purple, argillaceous halite; pale orange, clean halite; and translucent to grey clean halite. Bands are a few cm to several tens of cm thick. Dip of banding slightly variable, subhorizontal to 20°.

534.17-534.88 m: UPPER HALITE [banded subunit]. Coarse, translucent clean halite with bands of sylvite, grade 5-10%, with significant amounts of blue halite. Dip subhorizontal.

534.88-535.41 m: UPPER HALITE [banded subunit]. Sylvinite with 5-10% sylvite, significant interstitial grey-green clay. Low-angle dips.

535.41-535.98 m: UPPER HALITE [banded subunit]. As described for 534.17-534.88 m.

535.98-539.04 m: UPPER HALITE [banded subunit]. Pale orange, clean halite with bands of sylvitic halite. Dips variable, 50° to low angles.

539.04-546.15 m: UPPER HALITE [banded subunit]. Coarse, clean, light grey halite interbanded with coarse, clean, pale orange halite. A little anhydrite. Bands are subhorizontal.

546.15-548.31 m: UPPER HALITE [banded subunit]. Coarse, clean halite interbanded between light grey and pale orange units. Contains anhydrite bands generally <1 cm thick. Dip 30°-40°.

548.31-556.20 m: UPPER HALITE [banded subunit]. Coarse, clean, translucent to pale orange halite in bands 10-20 cm thick, interbedded with halite containing 2% sylvite and a little blue halite. Minor anhydrite as blebs and stringers. Lower contact is sharp, and dips 35°.

556.20-561.62 m: UPPER HALITE [banded subunit]. Red-brown argillaceous halite with <1% sylvite. Shallowly inclined to recumbent minor folds observed in this unit.

561.62-572.29 m: UPPER HALITE [banded subunit]. Coarse, clean, translucent to pale orange halite with trace sylvite.

572.29-574.28 m: UPPER HALITE [banded subunit]. As described for 556.20-561.62 m.

574.28-593.34 m: UPPER HALITE [banded subunit]. As described for 561.62-563.91 m.
593.34-595.43 m: UPPER HALITE [banded subunit]. As described for 556.20-561.62 m.

595.43-598.38 m: UPPER HALITE [banded subunit]. As described for 561.62-563.91 m.

598.38-598.63 m: UPPER HALITE [banded subunit]. Red-brown argillaceous halite with trace sylvite.

598.63-600.70 m: UPPER HALITE [banded subunit]. Coarse, clean, translucent to pale orange halite, with subhorizontal, mm-scale anhydrite stringers, trace sylvite and blue halite.

600.70-604.08 m: UPPER HALITE [banded subunit]. Coarse, clean translucent halite with trace sylvite and blue halite.

604.08-606.93 m: UPPER HALITE [banded subunit]. As described for 598.63-600.70 m.

606.93-608.67 m: UPPER HALITE [banded subunit]. Banded red-brown argillaceous halite and deep red halite with 1-2% sylvite, with bands of red-brown clay. Dip subhorizontal.

608.67-614.58 m: UPPER HALITE [banded subunit]. Medium to coarse, orange, clean halite with bands of dark grey argillaceous halite up to a few cm thick. Rare thin anhydrite stringers. Trace sylvite and blue halite.

614.58-615.12 m: UPPER HALITE [banded subunit]. Red-brown argillaceous halite.

615.12-616.39 m: UPPER HALITE [banded subunit]. Orange-brown argillaceous halite with subhorizontal anhydrite stringers <1 cm in thickness. Significant concentration of scattered sylvite crystals.

616.39-617.63 m: UPPER HALITE [banded subunit]. Red-brown argillaceous halite with significant concentrations of sylvite crystals. Dip subhorizontal to 20°.

617.63-632.88 m: UPPER HALITE [banded subunit]. As described for 615.12-616.39 m.

632.88-649.35 m: UPPER HALITE [banded subunit]. Orange, medium to coarse, clean halite with trace sylvite, interbedded with medium-grained sylvinite containing 15-20% sylvite with grey halite, significant blue halite, and disseminated and blebby grey-green clay.

649.35-706.93 m: ORE ZONE. Sylvinite containing up to 35% sylvite, with grey halite, large amounts of grey clay and trace blue halite. Significant yellow-green, fine-grained carnallite between 651.36-651.68 m.

706.93-710.19 m: ORE ZONE [lower gradational zone]. Low-grade sylvinite with bands of clean, orange halite.

710.19-717.07 m: ORE ZONE [lower gradational zone]. As described for 706.93-710.19 m, but with non-sylvitic bands becoming increasingly argillaceous downward.

717.07-750.46 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, with lots of grey-purple clay over first 2 m or so. Below that, red-brown clay with occasional blebs of grey-green clay. 20 cm of clean halite at base: lower contact irregular and diffuse.

750.46-753.99 m: TRANSITION ZONE. Argillaceous halite with grey clay becoming more common and replacing red-brown clay downward. Lower contact drawn at last bleb of red-brown clay.

753.99-785.03 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite with a little anhydrite, becoming cleaner toward base. Bands of anhydrite and clay have highly variable dips.

TOTAL DEPTH

Potash Company of America T-3
Summary Log

Commence logging at 244.00 m

244.00-257.12 m:	CAP ROCK. Red-brown siltstone and mudstone, also breccia with angular fragments of various red-brown sedimentary rock types (mudstone, siltstone, sandstone, grit etc). Clasts are angular to subrounded and up to 10 cm across. Matrix supported. Some intervals are slightly deformed, with a foliation defined by flattened clasts dipping approximately 20°.
257.12-265.59 m:	ORE ZONE. Approximately 15% sylvite with pale orange to grey halite and disseminated grey-green clay, interbedded with red-brown argillaceous halite and pale orange halite with scattered sylvite crystals.
265.59-471.00 m:	FOLDED ZONE. Interbedded red-brown argillaceous halite (Middle Halite) and orange to pale orange clean halite (lower gradational zone). Tight to isoclinal recumbent minor folds observed in core.
471.00-507.44 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite with anhydrite as stringers and jagged interstitial masses. Variable dips suggest that this unit is folded.
507.44-514.55 m:	TRANSITION ZONE. Interbedded grey-green argillaceous halite and pale orange to light grey, coarse, clean halite. Variable dips suggest that this unit is folded.
514.55-529.64 m:	BASAL HALITE. Clean to slightly anhydritic, translucent to dark grey, coarse to very coarse halite. Anhydrite as deformed bands and irregular blebs. Variable dips suggest that the unit is folded.
529.64-546.59 m:	TRANSITION ZONE. As described for 507.44-514.55 m.
546.59-611.25 m:	BASAL HALITE. Translucent to light grey, clean halite and dark grey, anhydritic halite. Dips are variable, and minor folds are observed in the core. A moderately well-developed schistosity is subparallel to bedding, where observed.

TOTAL DEPTH

Potash Company of America X-3
Summary Log

Commence logging at 617.46 m

617.46-618.22 m:	UPPER ANHYDRITE. Gypsiferous anhydrite with some grey clay and trace halite.
618.22-623.62 m:	UPPER HALITE [coarse subunit]. Coarse, light grey to dark grey argillaceous halite. Dip 50°-70°.
623.62-641.89 m:	UPPER HALITE [laminated subunit]. Bands up to a few cm thick of deep purple-red, argillaceous halite; coarse, clean, pale orange halite; and minor sylvinite; with mm-scale laminae of grey-green clay throughout. Bands of clay thickening up to 2 cm, and rare borate aggregates appearing, toward base. Shallowly inclined to recumbent folds are observed in this unit. Dips are highly variable.
641.89-653.14 m:	UPPER HALITE [sylvinite subunit]. As described for 623.62-641.89 m, with some zones of significant sylvite and blue halite concentration. Clay laminae becoming less common downward.
653.14-654.03 m:	UPPER HALITE [banded subunit]. 10-20 cm thick bands of coarse, clear, clean halite; coarse, pale orange, clean halite; and orange to deep purple-red, argillaceous halite.
654.03-656.13 m:	UPPER HALITE [banded subunit]. Banded sylvinite, argillaceous halite, and translucent to light grey clean halite. Some borate mineralization.
656.13-659.19 m:	UPPER HALITE [banded subunit]. Coarse, pale orange to light grey, clean halite with rare contorted anhydrite stringers. Sylvite as scattered crystals and also in bands of up to 1-2% sylvite, with significant amounts of blue halite imparting a blue-grey colour. A strong subhorizontal schistosity is sporadically developed.
659.19-660.39 m:	UPPER HALITE [banded subunit]. Deep orange halite containing blebs of red-brown and grey-green clay. Scattered sylvite crystals throughout.
660.39-662.17 m:	UPPER HALITE [banded subunit]. Clean, translucent to light grey halite with thin bands of low-grade sylvinite over the top metre or so.
662.17-665.02 m:	UPPER HALITE [banded subunit]. Sylvinite with significant blue halite and grey-green clay. Strong schistosity dips 30°.
665.02-666.16 m:	UPPER HALITE [banded subunit]. Coarse, orange to translucent, clean halite.
666.16-6778.76 m:	UPPER HALITE [banded subunit]. Interbanded clear, clean halite; deep-red argillaceous halite; and low-grade sylvinite. Strong subhorizontal schistosity, layering dips 30°. Significant sylvite and blue halite over the last 1.5 m.
678.76-684.01 m:	UPPER HALITE [banded subunit]. 10-30 cm thick bands of medium-coarse, clean to slightly sylvitic (<5%) halite; pale orange to red-brown argillaceous halite with scattered sylvite crystals and fibrous borates;

and red-brown argillaceous halite. Dip of schistosity and banding both around 20°.

684.01-690.73 m: UPPER HALITE [banded subunit]. Medium to coarse sylvinite grading 20% sylvite, with clear halite and up to 5% blue halite imparting a distinct blue-purple colour to the core.

690.73-691.22 m: UPPER HALITE [banded subunit]. Coarse, translucent halite with trace sylvite and blue halite.

691.22-693.32 m: UPPER HALITE [banded subunit]. Coarse, translucent halite with 5% sylvite and trace blue halite.

693.32-706.21 m: UPPER HALITE [banded subunit]. Bands of coarse, pale orange halite with scattered sylvite crystals; and low-grade sylvinite (5-10%) bands, less than 10 cm thick in general.

706.21-708.01 m: UPPER HALITE [banded subunit]. Sylvinite of variable grade up to 5%, with significant blue halite.

708.01-710.25 m: UPPER HALITE [banded subunit]. Coarse, clean, orange halite with trace sylvite and bands of anhydrite up to 5 cm thick, but in general <1 cm. Dip subhorizontal to 20°.

710.25-719.32 m: UPPER HALITE [banded subunit]. Coarse, slightly argillaceous and sylvitic orange-brown halite, interbedded with coarse, clean to slightly anhydritic, pale orange halite with trace sylvite. Dip 20°.

719.32-720.07 m: ORE ZONE. Sylvinite grading 30% sylvite, with grey halite and significant grey clay.

720.07-726.32 m: UPPER HALITE [banded subunit]. Coarse, clean, orange halite with bands of sylvinite associated with grey-green clay.

726.32-757.44 m: ORE ZONE. Sylvinite grading 30-35% sylvite, with grey halite, 2% blue halite and variable amounts of clay. Schistosity dips 30°-40°.

757.44-760.85 m: ORE ZONE. Coarse, clean, orange halite with trace sylvite and bands of red-brown argillaceous halite. The argillaceous bands may be schistose, schistosity parallel to banding at 30°.

760.85-761.41 m: ORE ZONE. Sylvinite, as described for 726.32-757.44 m.

761.41-761.65 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

761.65-762.25 m: ORE ZONE. Sylvinite, as described for 726.32-757.44 m.

762.25-762.85 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

762.85-774.41 m: ORE ZONE. As described for 726.32-757.44 m, but sylvite grade approximately 10-20%.

774.41-776.32 m: ORE ZONE. Coarse, clean halite with bands of sylvinite containing blue halite.

776.32-863.90 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, trace sylvite over first 3 m or so. Contains some bands of clean halite. Very coarse toward base. Schistosity subhorizontal to 20° throughout.

863.90-872.31 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Schistosity highly variable.

TOTAL DEPTH

Potash Company of America X-6
Summary Log

Commence logging at 851.93 m

851.93-853.46 m: CAP ROCK. Angular fragments of red-brown claystone and mudstone, up to a few cm across, in a red or green clay/mud matrix. Lower contact sharp.

853.46-871.03 m: PENOBSQUIS SALT. Very coarse, orange to grey, argillaceous halite with disseminated red-brown and grey-green clay. Grades into anhydritic argillaceous halite containing irregular lumps of anhydrite and grey-green or red-brown clay.

871.03-880.02 m: UPPER ANHYDRITE. Fine-grained, grey-blue, massive anhydrite. Some halite-filled fractures near top. Toward base, anhydrite is interbedded with bands of clear, coarse, crystalline halite. Lower contact is gradational.

880.02-884.38 m: UPPER HALITE [coarse subunit]. Translucent to dark grey, coarse, crystalline halite with bands of anhydrite and grey-green clay. Becoming pale orange in colour over the last metre or so. Lower contact gradational.

884.38-894.98 m: UPPER HALITE [finely laminated subunit]. Deep orange clean halite interbedded with dark grey argillaceous halite. mm-scale laminae of grey-green clay throughout. Minor folding is observed in this unit. Becoming slightly sylvitic and more clay-rich downward. Last 10 cm consists of pale orange halite with scattered crystals of sylvite.

894.98-896.68 m: UPPER HALITE [sylvinite subunit]. Fine- to medium-grained sylvinite grading a few % sylvite, with grey halite and grey-green clay. Weak schistosity is subhorizontal.

896.98-1044.72 m: UPPER HALITE [banded subunit]. Translucent to light grey to pale orange clean halite interbedded with red-purple argillaceous sylvitic halite. Bands are approximately 1 m thick. A strong schistosity is sporadically developed, and dips at low angles, subhorizontal to 30°.

1044.72-1049.18 m: ORE ZONE. Approximately 20% sylvite with orange to grey halite, trace blue halite, and large amounts of disseminated grey-green clay. Schistosity 20°-30°.

1049.18-1057.66 m: UPPER HALITE [banded subunit]. As described for 896.98-1044.72 m.

1057.66-1066.66 m: ORE ZONE. As described for 1044.72-1049.18 m. Grades into interbedded pale orange clean halite and red-purple argillaceous halite with scattered sylvite crystals at base.

1066.66-1073.51 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.

1073.51-1080.70 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

TOTAL DEPTH

Potash Company of America Z-4
Summary Log

Commence logging at 650.87 m

650.87-664.36 m:	UPPER ANHYDRITE. Massive, blue-grey, fine grained anhydrite. Contains halite-filled fractures.
664.36-670.79 m:	UPPER HALITE [coarse subunit]. Coarse to very coarse, clear to dark grey argillaceous halite with anhydrite along grain boundaries. Contains 1 cm thick bands of clay dipping 45° near top. Lower contact is sharp.
670.79-702.72 m:	UPPER HALITE [finely laminated subunit]. Orange to translucent clean halite interbedded with red-purple argillaceous halite and mm-scale laminae of grey-green clay. Variable dips and minor folding observed throughout.
702.72-742.78 m:	UPPER HALITE [sylvinite/banded subunit]. Medium grained, crystalline, pale orange to translucent, clean halite interbedded with red-purple argillaceous halite. Some folded anhydrite stringers up to 4 cm thick. Dip 10°-30°. Sylvite in rare bands and as scattered crystals.
742.78-822.39 m:	ORE ZONE. Orange-red sylvite 35-40%, with translucent to light grey halite and substantial blue halite. Schistose, with dips highly variable.
822.39-889.17 m:	ORE ZONE [lower gradational zone]. Pale orange halite with scattered crystals of sylvite decreasing in concentration downward, becoming interbedded with red-brown argillaceous halite toward base. Weak schistosity dips 20°-30°.
889.17-919.55 m:	MIDDLE HALITE [red-brown subunit]. Very coarse red-brown argillaceous halite.
919.55-941.72 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.
941.72-945.92 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
945.92-964.29 m:	ORE ZONE. Approximately 30% brick red sylvite with translucent to pale grey medium grained halite, significant blue halite, and locally large amounts of grey-green disseminated clay. Weakly schistosity is subhorizontal to 20°. Sylvite grade very low over last 3 m, as scattered crystals and thin sylvinite bands.
964.29-993.09 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite becoming very coarse grained downward. Schistosity strengthens and steepens to 45° toward base.
993.09-1015.11 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite. Schistosity variable 20°-45°.
1015.11-1020.71 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous and anhydritic halite. Schistosity variable, 20° near top to 50° at base.

TOTAL DEPTH

Potash Corporation of Saskatchewan 02-04
Summary Log

Commence logging at 512.76 m

512.76-516.61 m: MABOU GROUP. Red-brown and green-grey mudstone and claystone, dip 30°. Contains numerous gypsum veins dipping 20°-30° after 514 m or so. Some gypsum veins carry a down-dip slickenline lineation. Becomes increasingly heterogeneous and sheared in appearance downward, with some minor folding, becoming brecciated toward base.

516.61-528.49 m: UPPER ANHYDRITE. Blue-grey cryptocrystalline anhydrite, with halite crystals 2-4 cm across near top. Some bands of grey-brown clay and halite veins in top 3 m or so. Clay bands dip 20°-30° in general, but up to 50°. Becoming nodular toward base.

528.49-538.11 m: UPPER HALITE [coarse subunit]. Coarse to very coarse, translucent to dark grey to pale orange, clean to anhydritic halite.

538.11-549.14 m: UPPER HALITE [laminated subunit]. Pale to deep orange, coarse, clean halite with minor scattered sylvite crystals. Scattered platy, orange borate crystals and rare spheroidal aggregates of borate minerals. Laminae of clay up to 1 cm thick of grey-green clay and minor anhydrite. Dips variable, generally 20°-30°, but locally 45°.

549.14-567.05 m: UPPER HALITE [sylvinite subunit]. As described for 538.11-549.14 m, but with bands of sylvinite up to 20 cm thick, with concentrations of sylvite up to 40%. Minor carnallite and borates. Some borate aggregates (volkovskite) are sheared, taking on a schleiren-like shape. Some coarse to very coarse, red-rimmed transparent sylvite crystals up to 3 cm across in basal 10 m. Dips are highly variable, suggesting folding within the unit.

567.05-570.65 m: UPPER HALITE [banded subunit]. Bands of clear to light grey, coarse halite; pale orange, clean halite with minor sylvite bands and coarse to very coarse, red-rimmed, transparent sylvite crystals. Minor anhydrite and cubic, white borates. Dip 30°; sporadic schistosity also dips 30°.

570.65-600.13 m: UPPER HALITE [banded subunit]. 5-10 cm bands of orange, clean, coarse halite; red-brown argillaceous halite; and sylvinite with minor anhydrite bands. Bands get broader, up to 50 cm thick toward base. Sylvinitic layers have a schistosity dipping 30°, parallel to primary layering. Some anhydrite.

600.13-605.61 m: ORE ZONE. Medium to coarse sylvinite grading approximately 25% sylvite, with translucent to light grey halite, minor disseminated clay, and trace blue halite. Strongly lineated, plunge 10°-20°. Sharp contact with non-lineated halite below.

605.61-625.14 m: UPPER HALITE [sylvinite subunit]. Bands of orange, clean halite and sylvitic, argillaceous halite. Relatively high concentrations of borates, as orange spheroidal aggregates, scattered orange platy crystals, and white rosettes. Several bands of schistose halite and sylvinite dipping 45°-50°.

625.14-651.46 m: UPPER HALITE [banded]. Bands, on the order of 10s of cm to a few m thick, of clear, clean halite with trace sylvite; and dark grey to red-brown, argillaceous halite with minor sylvite and trace borate minerals. Becomes cleaner toward base, with bands of anhydrite up to 1 or 2cm thick. Schistosity steepening throughout, from 30° near top to 50° near base.

651.46-652.12 m: ORE ZONE. Medium to fine, slightly lineated sylvinite with greyish halite, trace blue halite and disseminated grey-green clay. Plunge of lineation slightly variable, 30°-50°.

652.12-655.83 m: ORE ZONE [lower gradational zone]. Clean, orange, coarse halite with bands of sylvinite and scattered sylvite crystals. Dips highly variable, some evidence of minor folding observed in core.

655.83-664.42 m: ORE ZONE. Sylvinite grading 25-30%, with grey halite, trace blue halite and small amounts of disseminated grey-green clay. Not strongly schistose or lineated, but does contain some discrete clay-rich, schistose bands, with schistosity dipping 40°. Lower contact is gradational, with sylvinite becoming coarser, and interbanded with 10-20 cm scale bands of clean, coarse halite with scattered crystals of sylvite. Very coarse over last 2 m or so, and containing very coarse, red-rimmed, transparent crystals of sylvite up to 2 cm across.

664.42-690.00 m: MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite, with some bands and aggregates of sylvite crystals, some with red rims.

690.00-712.27 m: MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.

712.27-757.76 m: BASAL HALITE. Coarse, clean, schistose halite, grading into coarse to very coarse halite in a fine- to medium-grained schistose matrix, and finally into coarse halite with bands of fine- to medium-grained anhydritic halite. [similar to that described in B-3].

757.76-840.43 m: BASAL ANHYDRITE. Massive, blue-grey, cryptocrystalline anhydrite.
840.43-857.10 m: MACUMBER LIMESTONE

857.10-857.24 m: HILLSBOROUGH FORMATION

TOTAL DEPTH

Potash Company of America DD-4A
Summary Log

Commence logging at 688.08 m

688.08-698.12 m: UPPER ANHYDRITE. Massive, blue-grey, fine-grained anhydrite interbedded with bands of clean and argillaceous halite up to a few tens of cm thick. Dips are highly variable.

698.12-698.21 m: UPPER HALITE [coarse subunit]. Coarse, clean, clear halite. Lower contact dips 25°.

698.21-711.52 m: UPPER HALITE [laminated subunit]. Bands, <10 cm thick, of orange, clean, coarse halite and sylvinite. Contains mm-scale laminae of grey clay throughout. Some asymmetric folds and fold hinges observed in core.

711.52-718.36 m: UPPER HALITE [banded subunit]. 10 cm-50 cm thick bands of clean, orange halite with trace sylvite; Sylvinite grading <10% sylvite; and argillaceous halite with scattered crystals of sylvite.

718.36-719.20 m: UPPER HALITE [banded subunit]. Carnallitic halite.

719.20-722.13 m: UPPER HALITE [banded subunit]. Sylvinite, grading 35-40% sylvite with greyish coarse halite, disseminated grey clay, and significant blue halite.

722.13-722.93 m: UPPER HALITE [banded subunit]. Approximately 20% sylvite, with varying amounts of yellow carnallite.

722.93-723.23 m: UPPER HALITE [banded subunit]. Sylvinite as described for 719.20-722.13 m.

723.23-726.55 m: UPPER HALITE [banded subunit]. Carnallitic halite, with a few % sylvite dying out after first metre or so.

726.55-728.28 m: UPPER HALITE [banded subunit]. Coarse to very coarse sylvitic, carnallitic halite.

728.28-736.73 m: UPPER HALITE [banded subunit]. Clean, coarse, translucent to pale orange halite with sylvite and carnallite in narrow bands, often associated with argillaceous halite. Some grey-green clay blebs.

736.73-743.93 m: UPPER HALITE [banded subunit]. As described for 728.28-736.73 m, with rare anhydrite bands up to 5 cm thick. Dips 50°.

743.93-747.85 m: UPPER HALITE [banded subunit]. Very coarse, blue-violet halite and red sylvite, with medium-grained, grey, argillaceous halite aggregates. Schistosity highly variable.

747.85-815.37 m: UPPER HALITE [banded subunit]. Bands of clean, orange halite; sylvitic halite; and argillaceous halite. Anhydrite stringers throughout. Dips highly variable.

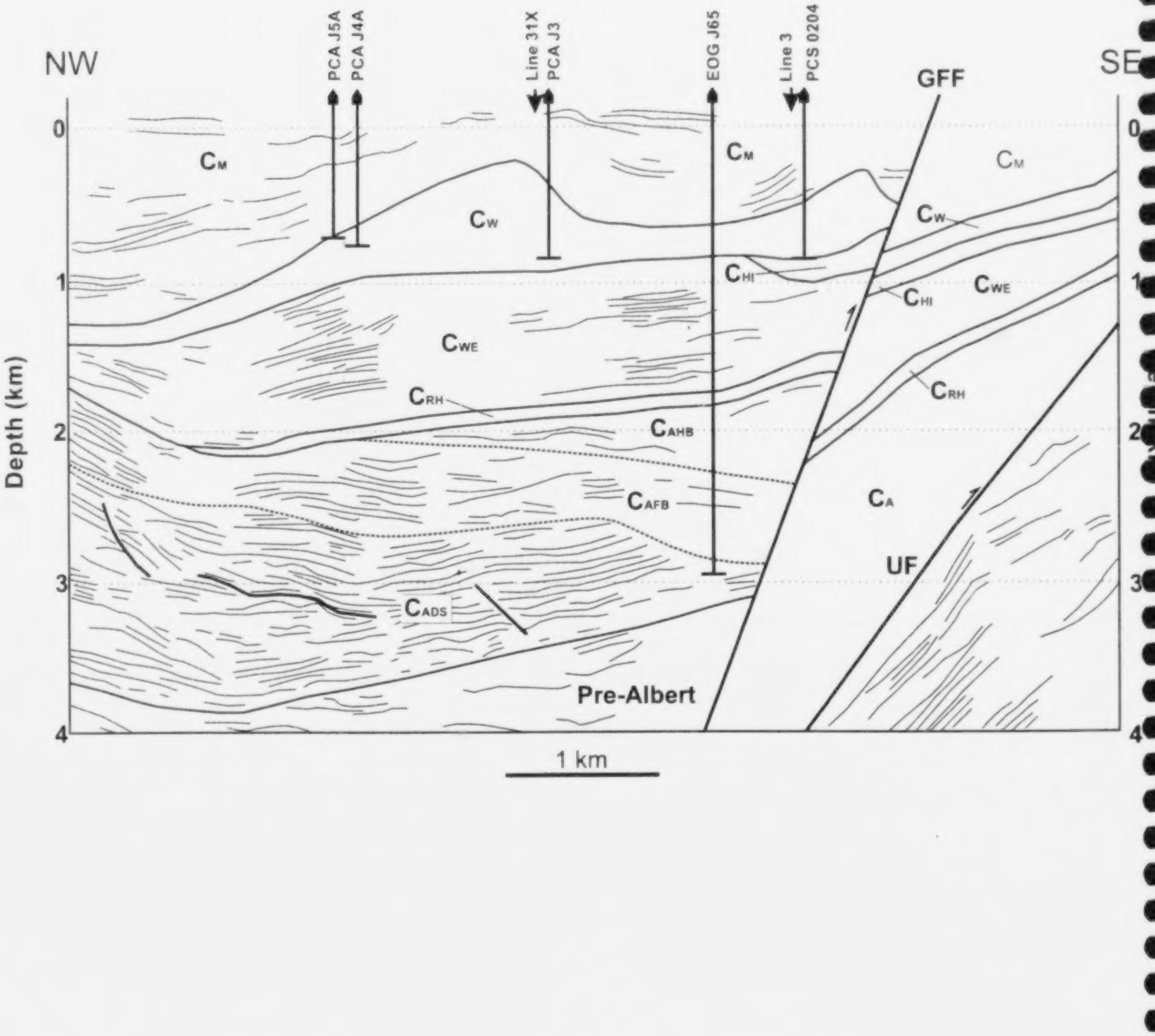
815.37-821.50 m:	ORE ZONE. Sylvinite grading 30% sylvite with grey halite, trace blue halite, and disseminated grey-green clay.
821.50-827.65 m:	MIDDLE HALITE [red-brown subunit]. Red-brown argillaceous halite.
827.65-836.09 m:	MIDDLE HALITE [grey-green subunit]. Grey-green argillaceous halite.
836.09-842.42 m:	BASAL HALITE. Coarse, clean, translucent to light grey halite.

TOTAL DEPTH

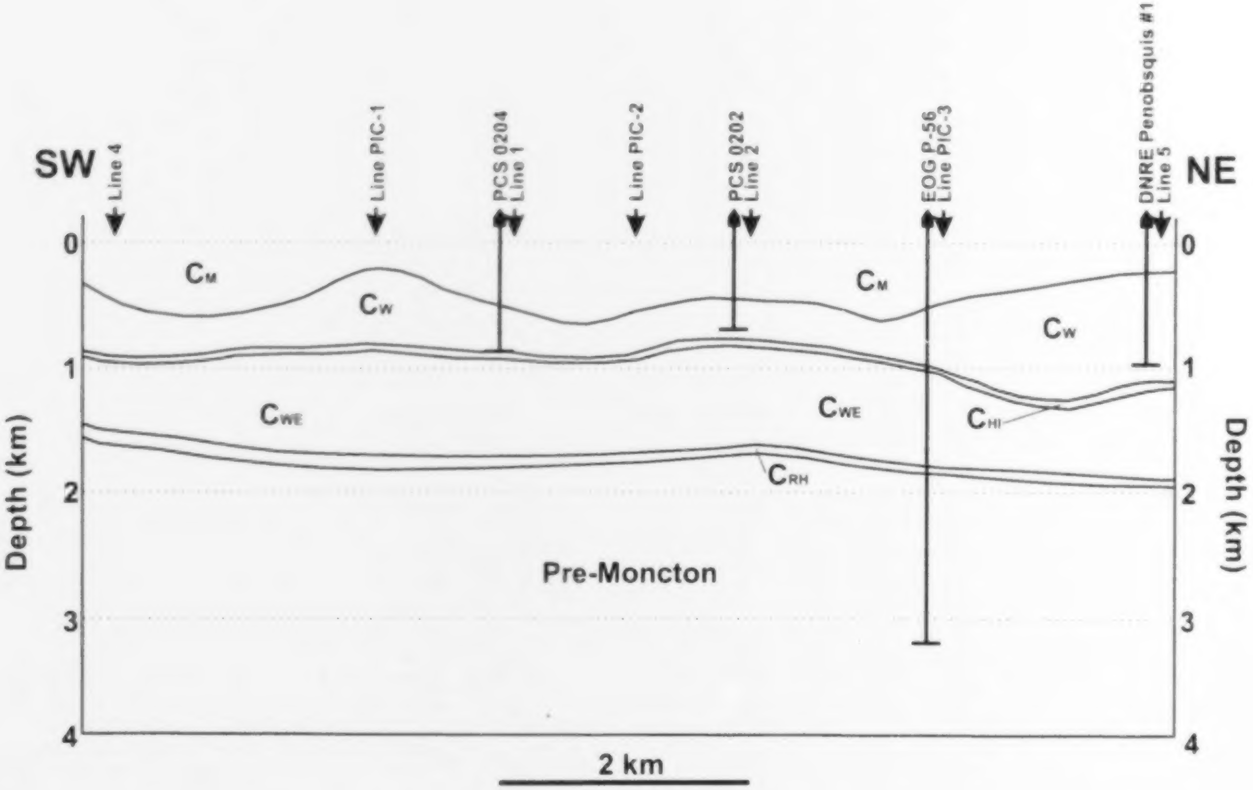
APPENDIX 2

Interpretations of Seismic Reflection Profiles

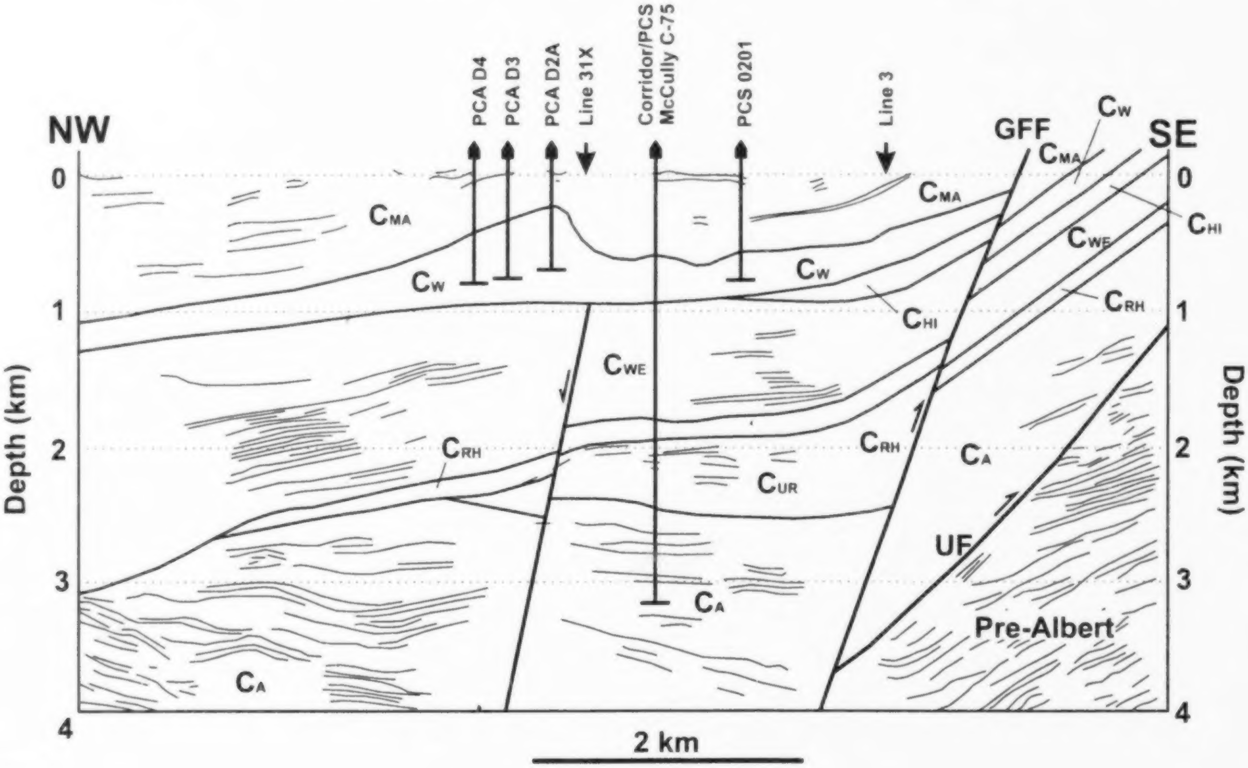
INTERPRETATION OF CORRIDOR RESOURCES INC. LINE 1


NW
SE
PCA J5A
PCA J4A
Line 31X
PCA J3
EOG J65
Line 3
PCS 0204
GFF
C_M
C_M
C_M
C_W
C_W
C_{HI}
C_{HI}
C_{WE}
C_{WE}
C_{RH}
C_{RH}
C_{AHB}
C_{AFB}
C_A
C_{ADS}
UF
Pre-Albert
Depth (km)
0
1
2
3
4
0
1
2
3
4
1 km

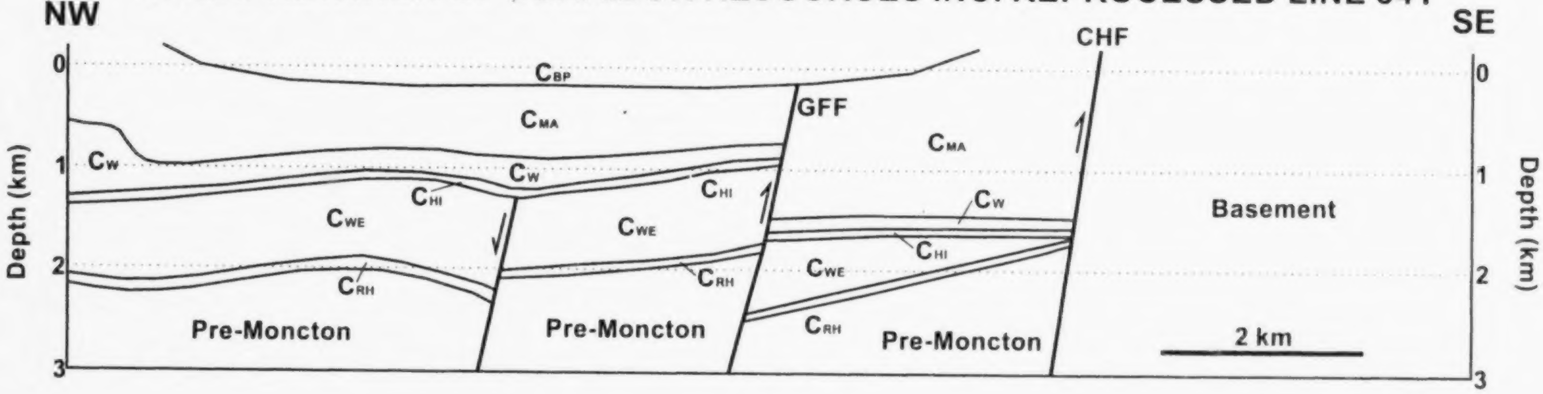
INTERPRETATION OF CORRIDOR RESOURCES INC. LINE 3


SW
NE
Line 4
Line PIC-1
PCS 0204
Line 1
Line PIC-2
PCS 0202
Line 2
EOG P-56
Line PIC-3
DNRE Penobsquis #1
Line 5
0
1
2
3
4
Depth (km)
C_M
C_W
C_{WE}
C_{HI}
C_{RH}
Pre-Moncton
2 km

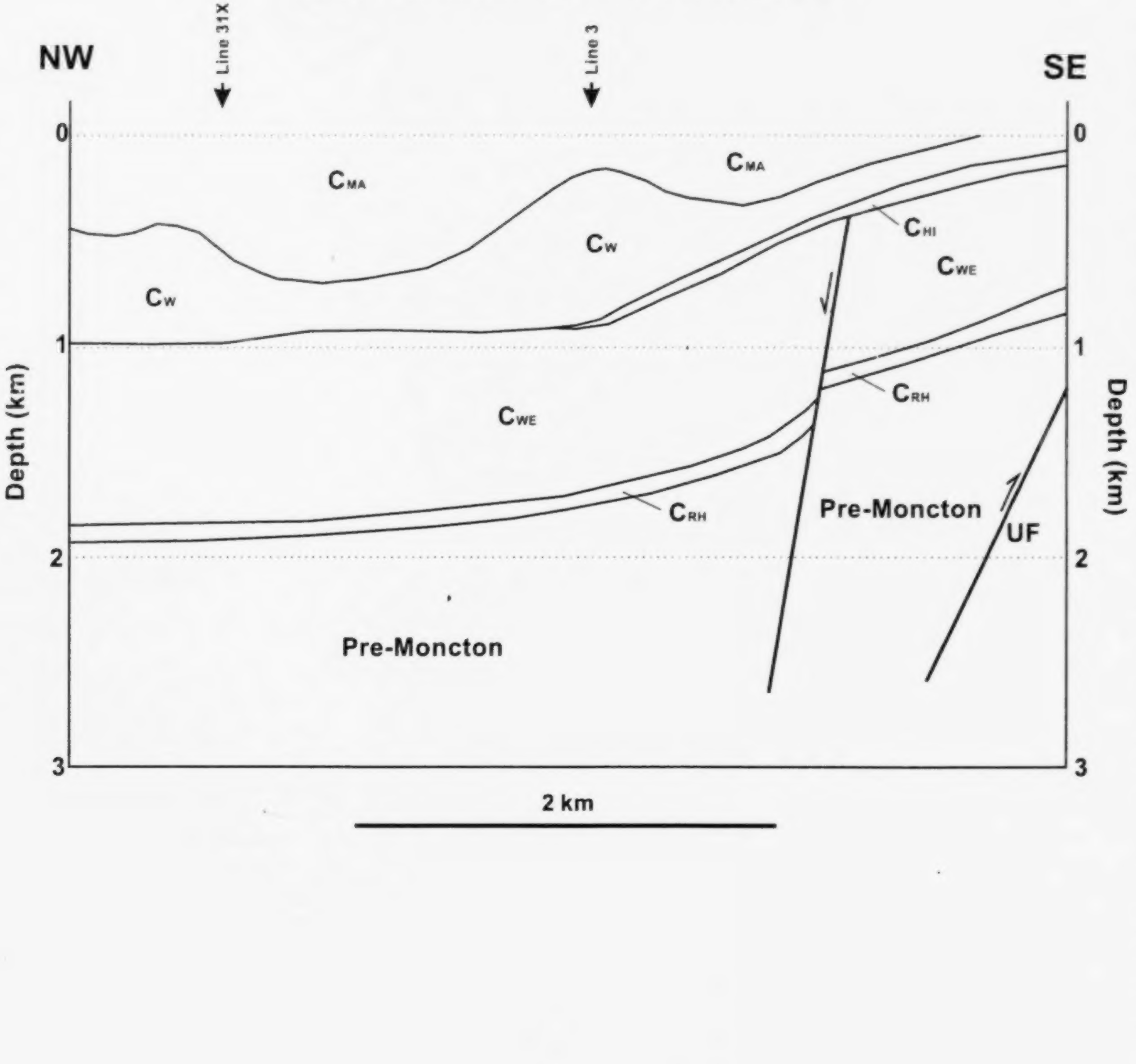
INTERPRETATION OF CORRIDOR RESOURCES INC. LINE 4


PCA D4
PCA D3
PCA D2A
Line 31X
Corridor/PCS McCully C-75
PCS 0201
Line 3
NW
SE
GFF
CW
CMA
CHI
CWE
CRH
CUR
CA
UF
Pre-Albert
Depth (km)
0
1
2
3
4
2 km

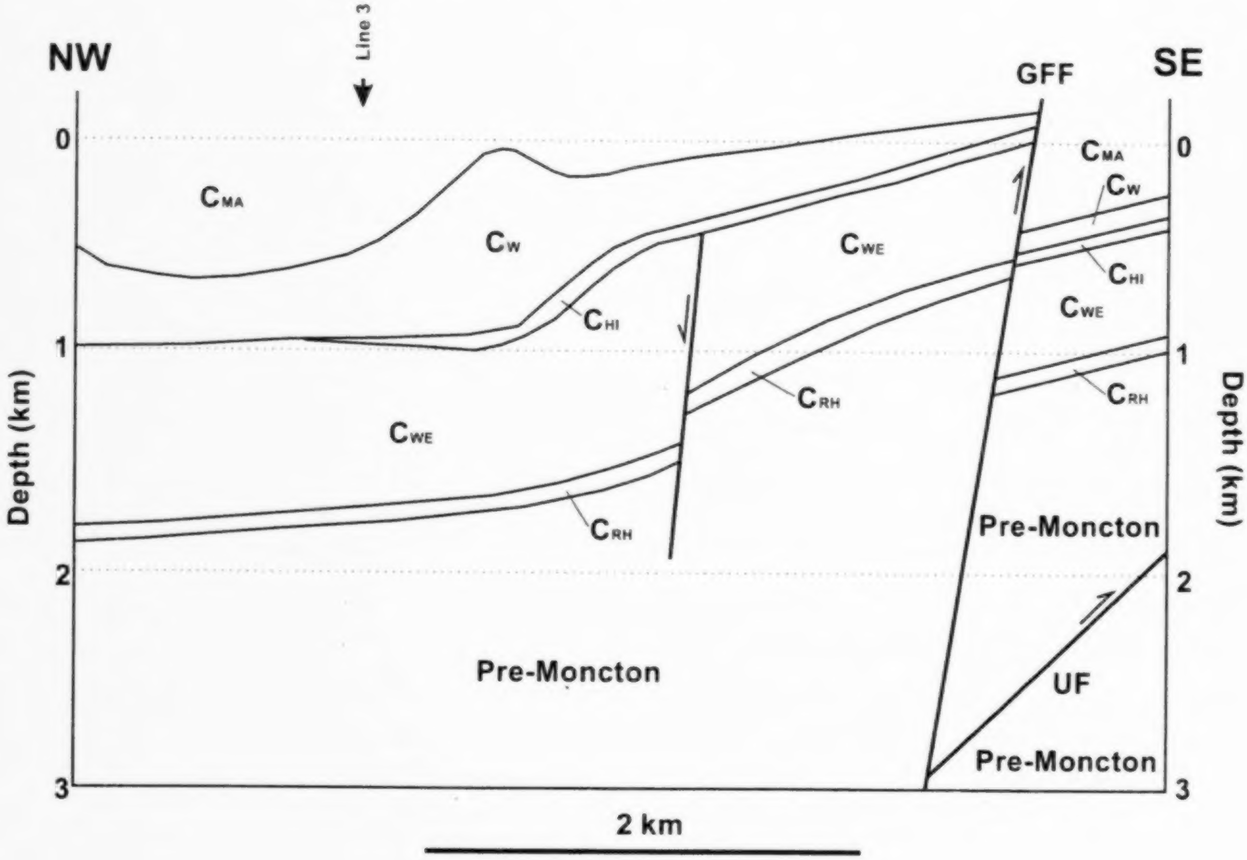
INTERPRETATION OF CORRIDOR RESOURCES INC. REPROCESSED LINE 34Y


NW
SE
CHF
GFF
C_{BP}
C_{MA}
C_{MA}
C_W
C_W
C_W
C_{HI}
C_{HI}
C_{HI}
C_{WE}
C_{WE}
C_{WE}
C_{RH}
C_{RH}
C_{RH}
Pre-Moncton
Pre-Moncton
Pre-Moncton
Basement
2 km
Depth (km)
0
1
2
3
Depth (km)
0
1
2
3

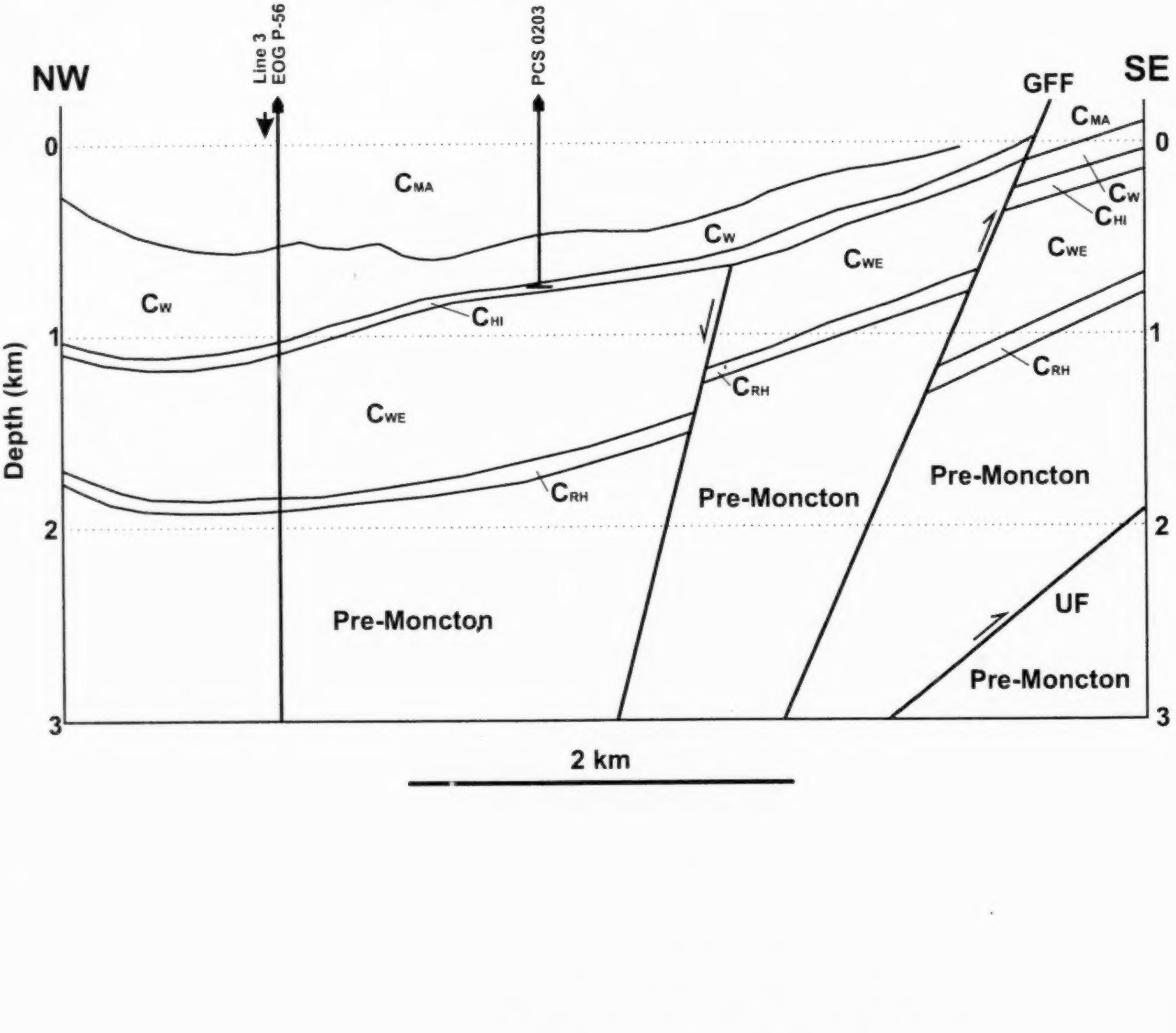
INTERPRETATION OF POTASH CORPORATION OF SASKATCHEWAN INC. LINE PIC-1


NW
Line 31X
Line 3
SE
0
1
2
3
Depth (km)
C_{MA}
C_{MA}
C_W
C_W
C_{HI}
C_{WE}
C_{WE}
C_{RH}
C_{RH}
Pre-Moncton
Pre-Moncton
UF
0
1
2
3
Depth (km)
2 km

INTERPRETATION OF POTASH CORPORATION OF SASKATCHEWAN INC. LINE PIC-2


Line 3
NW
SE
GFF
0
1
2
3
Depth (km)
C_{MA}
C_{W}
C_{WE}
C_{HI}
C_{RH}
Pre-Moncton
UF
2 km

INTERPRETATION OF POTASH CORPORATION OF SASKATCHEWAN INC. LINE PIC-3


Line 3
EOG P-56
PCS 0203
NW
SE
GFF
0
1
2
3
Depth (km)
CMA
CW
CHI
CWE
CRH
Pre-Moncton
UF
2 km

OVERSIZE MAP NOT FILMED

CARTE SURDIMENSIONNÉE NON REPRODUITE

Micromedia
ProQuest

20 Victoria Street
Toronto, Ontario M5C 2N8
Tel: (416) 362-5211
Toll Free: 1-800-387-2689
Fax: (416) 362-6161
Email: info@micromedia.on.ca